Technical Support Document

for

Wisconsin's Thermal Water Quality Rules

8/2008
DRAFT

Prepared By:
Mike Wenholz, Wisconsin Department of Natural Resources

Questions regarding this technical support document may be directed to:

Thermal Rules Technical Support
Water Evaluation Section
Bureau of Watershed Management
Wisconsin Department of Natural Resources
101 South Webster Street, WT/3
P.O. Box 7921
Madison, Wisconsin 53707-7921

Or find additional contact information online at:

http://www.dnr.state.wi.us/org/water/wm/wqs/staff.htm

You can view current versions of Administrative Code rules NR 102 and NR 106 online via:

http://folio.legis.state.wi.us

Click "quick find"
Click "go to admin code section or chapter"
Type "ch. nr 102" or "ch. nr 106"

TABLE OF CONTENTS

GENERAL

INFORMATION

INTRODUCTION

The purpose of this Technical Support Document (TSD) is to support the proposed thermal rules revisions in Chapters NR 102 and NR 106 of Wisconsin Administrative Code by providing relevant background information, including an explanation of why individual revisions are being proposed, and explaining how the revisions were developed.

Most of the proposed revisions to Chapters NR 102 and 106 pertaining to thermal discharges are contained within newly created subchapters. "Subchapter II - Water Quality Standards for Temperature" is in Chapter NR 102, and "Subchapter V - Effluent Limitations for Temperature" and “Subchapter VI – Alternative Effluent Limitations for Temperature” are in Chapter NR 106. These thermal-based subchapters of Chapters NR 102 and 106 are the primary mechanisms for protecting the surface waters of the State of Wisconsin from the impacts of heated discharges.

Chapter NR 102 describes the use categories for surface waters of the state, along with the water quality criteria necessary to support those uses. The water quality criteria in Chapter NR 102 are used in calculating effluent limitations. Ch. NR 106 contains the methodologies for determining whether or not a water quality-based effluent limitation for temperature is necessary for a given discharge and for calculating water quality-based effluent limitations in WPDES discharge permits.

The TSD is intended to be a valuable resource for anyone interested in understanding or using Wisconsin’s thermal rules of Chapters NR 102 and NR 106 for surface waters. Please contact the Water Evaluation Section of the Wisconsin Department of Natural Resources (the Department) if you have any questions or comments regarding this TSD. Additionally, you may refer to “Answers to Common Questions Regarding Wisconsin’s Thermal Water Quality Rules” for additional information.

WHO THE THERMAL RULES APPLY TO

The thermal-based sections of Chapter NR 102, Wisconsin Administrative Code, apply to any discharger of heat to any surface water of Wisconsin.

The thermal-based sections of Chapter NR 106 Subchapter V, Wisconsin Administrative Code, apply to point sources which discharge wastewater, including cooling and non-contact cooling waters, to surface waters of Wisconsin which are elevated in temperature or consist of an associated heat load; except where thermal effluent limitations are established according to the procedures in Chapter NR 106 Subchapter VI.

Additionally, the thermal-based sections of Chapter NR 102 and NR 106 may apply to dischargers of heat to water bodies that flow into a water of Wisconsin.

OVERVIEW OF WATER QUALITY STANDARDS

Basis for Water Quality Standards

Section 303, 304, and 305 of the Clean Water Act (Federal Water Pollution Control Act) of 1972, and its Amendments of 1977 and 1987 provide the statutory basis for developing, implementing, updating, and reporting state water quality standards.

Chapters NR 102, 103, 104, and 105, pursuant to State Statute 281, establish water quality standards in Wisconsin.

What Water Quality Standards Do

- Define the water quality goals of a waterbody
- Provide the regulatory basis for creating water quality-based effluent limits and controls that go beyond treatment technology (categorical)-based limits
- Apply to all Wisconsin surface waters

What Water Quality Standards Include

1. Use Designations
    - Set the goals of purpose for a waterbody (i.e. What will a given waterbody be used for?), thus determining the appropriate criteria to protect that purpose
    - Based on the potential of a waterbody
    - Types of uses include: public water supply, protection and propagation of aquatic life and wildlife, recreation, agriculture, and industry
    - Included within NR 102 (regulations) and NR 104 (variances)

2. Water Quality Criteria
    - Highest allowable concentration of pollutants in, or the specified conditions of, a waterbody that do not represent any appreciable risk of adverse effect to aquatic organisms or human health
    - Expressed either numerically or in narrative
    - When met, the criteria should protect the designated use
    - Included within NR 102, 104, and 105

3. Anti-Degradation Policy
    - Prevent water quality from degrading as a result of human-induced pollutant loads
    - Assure that new or increased discharges do not impair designated uses
    - Included within NR 102.05 and NR 207

Types of Water Quality Standards Applicable to Wisconsin Surface Waters

- Public Health and Welfare Standards
- Wild and Domestic Animal Standards
- Recreational Use Standards
- Fish and Aquatic Life Standards

Relation of Water Quality Standards to Permitting

Section 402 of the Clean Water Act (Federal Water Pollution Control Act) of 1972, and its Amendments of 1977 and 1987 provide the statutory basis for establishing the National Pollutant Discharge Elimination System (NPDES) permit program. Chapter NR 106, pursuant to State Statute 283 establishes the procedures for calculating water quality-based effluent limits (WQBELs) for point discharges, as well as how these limits are to be included in Wisconsin Pollution Discharge Elimination System (WPDES) permits. WQBELs are calculated and imposed in permits to maintain the established water quality standards.

BRIEF HISTORY OF AQUATIC THERMAL RULES IN WISCONSIN

The following is a brief summary of the developments that gave rise to Wisconsin's existing thermal rules and the need for their revision:

The Water Quality Act of 1965 required that all states adopt water-quality standards. Within this framework, the Lake Michigan Enforcement Conference (LMEC) was established in 1968 with the purpose of developing pollution control guidelines for nuclear power plants on Lake Michigan. Under this direction, the LMEC attempted to establish numerical limits for man-made thermal discharges, but found insufficient data to do so, and instead recommended intensive field and laboratory studies to determine the damage potential of thermal discharges.

In 1971, the State of Wisconsin Natural Resources Board (NRB) required two-year environmental impact studies at several power plants on Lake Michigan to assess the impacts of thermal discharges, as well as various corrective methods to minimize those impacts.

In 1972, Public Law (PL) 92-500, the "Federal Water Pollution Control Act Amendments of 1972", became effective. This law required states to adopt acceptable effluent limitations as part of their pollution control efforts. U.S. EPA was to publish the effluent limitation guidelines in the Federal Register, while the states would be responsible for implementing them. In addition, Section 316(a) of PL 92-500 allowed dischargers a variance from thermal discharge limitations if they could demonstrate that the indigenous aquatic life would be protected. Similarly, Section 316(b) required that cooling water intake structures reflect the best technology available in design and location in order to minimize impingement and entrainment losses of aquatic organisms.

In 1973, Wisconsin set forth a proposal to revise the state's water-quality standards so that they would be in accordance with PL 92-500.

In 1975, the standards in Chapter NR 102 took effect and required that any discharge containing heat be restricted such that any change in the receiving water be limited to a 5°F rise above ambient background temperature for flowing water and a 3°F rise above ambient background temperature for lakes. The maximum temperature allowed depended on the specified water body.

Subsequently in 1975, Wisconsin Electric Power Company, Wisconsin Public Service Corporation, and Wisconsin Power and Light Company filed legal suits against the Department of Natural Resources (the department) on the grounds that the thermal provisions of Chapter NR 102 exceeded the stringency of the Federal Effluent Limit Regulations, and thus violated section 147.021 Stats. State standards allow only water-quality-based effluent limits (and not categorical, treatment-technology-based limits) to be stricter than Federal guidelines. In 1979, the Wisconsin Supreme Court interpreted the language pertaining to temperature in Chapter NR 102 as categorical-based effluent limitations, and thus the thermal provisions of Chapter NR 102 were not upheld.

The issue was not revisited again until 1991 and 1992, when the department attempted to issue permits for Wisconsin Power and Light Company's Rock River and Wisconsin Electric Power Company's Valley power plants, respectively. U.S. EPA objected to the issuance of these permits on grounds that they were inadequate for protecting aquatic life from thermal discharges.

In light of these developments, the department and U.S. EPA concurred on the need to revise the provisions of Chapter NR 102 that relate to temperature. In 1994 the DNR received an EPA grant to develop defensible thermal standards and used it to hire Suzy Salib. A Technical Advisory Committee – Thermal Standards Revisions Advisory Committee (AC) - was formed to generate new thermal standards, with Suzy as the AC's chair. A primary mission of the AC was to develop scientifically sound and water-quality based standards that protect the biological, chemical, and physical quality of the receiving water and ultimately lead to enforceable water-quality-based effluent limitations for thermal discharges.

From 1994 to 1997 the AC met to fulfill its mission. As a product of the AC's work, a proposed thermal standards rule revisions package was developed and sent out for public hearing and comment in 1998. The department received many relevant comments in 1998 and early 1999. From 1999 to early 2001 progress on finalizing the thermal standards rule revisions was halted due to external opposition and internal issues related to reorganization, retirement, and reassignment of staff.

In May 2001 the thermal standards rule revisions effort was re-established when Mike Wenholz was hired and charged to re-convene the AC and finalize thermal rules revisions. The reconvened AC, as well as a newly formed subgroup (the Criteria Development Work Group - CDWG), has met and worked, much of the time regularly, since October 2001 on making revisions to Wisconsin's thermal rules, using the 1998 draft rules as a starting point. The mission of the reconvened AC and CDWG includes that of the original AC, but was expanded to insure the thermal rules revisions will be environmentally protective, scientifically and legally defensible, and reasonably implementable.

After several years of meetings, a draft rule package was prepared and brought out for public hearing and comment. Many comments were received from a wide variety of interests. Numerous revisions were made to the draft rules based on the comments received, and the final rule package was developed.

MIXING ZONES FOR THE THERMAL RULES

The department allows mixing zones to be considered in regulating effluent discharges to waters of the State, however certain conditions must be met to prevent the allowance of a mixing zone from causing deleterious effects to aquatic life or their habitat. Subsection NR 102.05(3) details the conditions mixing zones must meet. A mixing zone in a unidirectionally flowing waterbody is really a theoretical area determined largely by the amount of stream flow and effluent flow. A mixing zone in a lake is a prescribed area based on U.S. Fish and Wildlife models. In either case the mixing zone is implemented as a part of a conservation of mass, dilution-based equation. See the Chapter NR 106 section for additional details.

Since heat is a nonconservative pollutant that dissipates (i.e. is lost, rather than simply being diluted) within the waterbody it is discharged into, the thermal rules expand the allowance of mixing zones for regulating thermal discharges to waters of the State. Conservative pollutants, such as toxic pollutants, are allowed a mixing zone for the regulation of chronic criteria, but are not allowed a mixing zone for the regulation of acute criteria. However, a mixing zone is allowed for the regulation of both acute and sub-lethal thermal criteria. The proposed rules include the same mixing zone area for the regulation of both acute and sub-lethal thermal criteria, but propose the criteria be applied differently. The acute criteria are to be applied as daily maximum values. The sub-lethal criteria are to be applied as 7-day average values.

CHAPTER NR 102

0

OVERVIEW OF REVISIONS AND ADDITIONS

The primary revisions proposed for Chapter NR 102 include the following:

- Rewording and additions are included in the "Fish and Aquatic Life Uses" and "Criteria for Fish and Aquatic Life" subsections of ch. NR 102.04, primarily to help distinguish and outline specific thermal-related details between the different surface water designated uses of Wisconsin.
- Rewording and numerical criteria are included for protection of recreational and public health and welfare uses under ch. NR 102.04.
- The mixing zone subsection of ch. NR 102.05 is updated to address thermal discharge applications.
- An entirely new Subchapter is added that outlines water quality standards for temperature. Significant components of this new subchapter include:
  - The Great Lakes community inclusion as a water use category for temperature.
  - A numeric water quality-based criterion for limited aquatic life uses that are not wastewater effluent channels.
  - Cold shock and rate of temperature change narrative standards.
  - Default ambient temperatures and water quality criteria set for different water body types of Wisconsin, including Great Lakes waters.
  - Options for establishing site-specific ambient temperatures and/or water quality criteria for temperature.

A total of 720 references/sources of information were used in and support the revisions in Chapter NR 102.

CATEGORIES OF STANDARDS APPLICABLE TO THERMAL RULES

Categories of standards applicable to the thermal rules, as listed in section NR 102.23, are:

Public Health and Welfare
Fish and Other Aquatic Life (i.e. Cold and Warm Water Communities)
Limited Forage Fish Communities
Limited Aquatic Life Communities
Great Lakes Communities

The definitions for each of these categories (uses or communities) are in section NR 102.04, except for the definition of the Great Lakes subcategory (community) which is contained in subsections NR 102.22(6) and NR 102.25(5). The Great Lakes subcategory is only applicable to the thermal rules, while the other subcategories are applicable to not only the thermal rules, but others (such as those for regulating toxic substances), as well.

Water quality standards for temperature have been established for each category (use or community). In addition to the categories listed above, water quality standards for temperature are established for several specific water uses or communities, some of which are subsets of the warm water subcategory listed above. The complete list of specific water uses that water quality standards for temperature have been established for in subchapter II of Chapter NR 102 is provided below:

Water Body Use or Community	Subset of Warm Water Community?
Cold Water Unidirectional Flowing Water Bodies	No
Large Warm Water Unidirectional Flowing Water Bodies	Yes

Small Warm Water Unidirectional Flowing Water Bodies	Yes
Limited Forage Fish Unidirectional Flowing Water Bodies	No
Northern Inland Lakes	No
Southern Inland Lakes	No
Mississippi River	Yes
Rock River	Yes
Upper Wisconsin River	Yes
Lower Wisconsin River	Yes
Lower Fox River	Yes
Southern Green Bay	No
Northern Green Bay	No
Northern Lake Michigan	No
Southern Lake Michigan	No
Lake Superior	No
Chequamegon Bay	No
Limited Aquatic Life – not a wastewater effluent channel or wetland	No
Limited Aquatic Life – wastewater effluent channel	No

As it pertains to thermal discharges, establishment and application of water quality standards for each subcategory and additional water use listed above is considered suitable for the protection and propagation of a balanced fish and other aquatic life community, as provided in the federal water pollution control act amendments of 1972 (P.L. 92-500; 33 USC 1251 et seq.).

Descriptions for each of the water body uses or communities listed above and in other tables within this document, as well as their acronyms, are provided below, and in Section NR 102.24 and in Tables 2 - 7 of subchapter II of Chapter NR 102.

Cold = waters with a fish and aquatic life use designation of "cold"
Warm -Large = waters with a fish and aquatic life use designation of "warm" and unidirectional 7Q10 flows ≥ 200 cfs (129 mgd)
Warm - Small = waters with a fish and aquatic life use designation of "warm" and unidirectional 7Q10 flows < 200 cfs (129 mgd)
LFF = waters with a fish and aquatic life use designation of "limited forage fish"
NIL = Northern Inland Lakes = applicable for those lakes north of State Highway 10
SIL = Southern Inland Lakes = applicable for those lakes south of State Highway 10
Mississippi River = applies to any portion of Wisconsin's Mississippi River reach
Rock River = applies to waters downstream of Lake Koshkonong
Upper Wisconsin River = applies to waters upstream of Petenwell Dam
Lower Wisconsin River = applies to waters downstream of Petenwell Dam to the confluence with the Mississippi River
Lower Fox River = applies to waters downstream of the Lake Winnebago outlet
SGB = Southern Green Bay = Green Bay waters south of the Brown County line to the Fox River mouth
NGB = Northern Green Bay = Green Bay waters north of the Brown County line to the northernmost point on Washington Island
SLKMI = Southern Lake Michigan = Lake Michigan waters south of the Milwaukee River mouth (downtown Milwaukee)
NLKMI = Northern Lake Michigan = Lake Michigan waters north of the Milwaukee River mouth (downtown Milwaukee)
LKSUP = Lake Superior = waters in Lake Superior except those in Chequamegon Bay
CB = Chequamegon Bay = waters within the region enclosed by Chequamegon Point and a straight line west to the mainland
GL = general reference to Great Lakes waters of Wisconsin
LAL = Limited Aquatic Life community
LAL – not a wastewater effluent channel or wetland = pertains to all LAL waters that are not categorized as wastewater effluent channels or wetlands (that are to be regulated under NR 103) in section NR 104.02
LAL – wastewater effluent channels = pertains to all LAL waters that are categorized as wastewater effluent channels in paragraph NR 104.02(1)(c)

DEFAULT AMBIENT TEMPERATURE DEVELOPMENT

General

In order for the thermal standards and effluent limitations to be water quality-based, default ambient temperatures representative of the various types of waters in Wisconsin must be included in the thermal rules. Both the acute and sub-lethal water quality criteria are tied to ambient temperatures. Since Wisconsin has numerous water body types (as listed in the "Categories of Standards Applicable to Thermal Rules" section) it is important to include ambient water temperatures from all the different water body types in order to develop a complete set of appropriate default ambient temperatures.

Data

8848 monthly average ambient water temperatures from a total of 93 monitoring stations in Wisconsin were used to develop the proposed default monthly ambient temperatures for the different water body types. Data was collected by or reported to the U.S. Geological Survey, Wisconsin DNR, Green Bay Metropolitan Sewerage District, the UW Center of Limnology, and Wisconsin Power and Light. All temperatures were collected between October 1987 and December 2002, incorporating data from relatively cold, warm, and "normal" years in an effort to develop default ambient temperatures representative of Wisconsin's various water body types. 5398 monthly average ambient temperatures from 65 monitoring stations were used to develop the proposed default ambient temperatures for the 9 riverine water body classifications. 2440 monthly average ambient temperatures from 18 monitoring stations were used to develop the proposed default ambient temperatures for the 2 inland lake water body classifications. 1010 monthly average ambient temperatures from 10 monitoring stations were used to develop the proposed default ambient temperatures for the 6 Great Lakes water body classifications.

Hard copies of the data used to develop the default acute water quality criteria are provided in a red three-ring binder labeled "Ambient Temperature Development". The data includes monthly average temperatures at each monitoring station and the monthly geometric mean per water use classification.

Default Ambient Temperature Development

Default ambient temperatures are developed according to the following steps:

1. Locate monthly average ambient temperature data for Wisconsin water bodies.
    a. Include water bodies that represent each of the non-LAL water body uses or communities listed on pages 11-12, if possible.
    b. Include data collected between October 1987 and December 2002. October 1987 was the start of USGS Water Year 1988. The analyses were in large part completed by the end of 2002. It was determined that a collection of 15 year's worth of water temperature data would be representative of the gamut of typical water temperatures in Wisconsin, including relatively cold, relatively warm, and average temperature years.
2. Enter "1." into a database or spreadsheet.
3. Organize "2." into each of the non-LAL water body uses or communities listed on pages 11-12.
4. Organize all data by year.
5. Organize all data by month.
6. Calculate the geometric mean of all monthly average temperatures for each month (i.e. January, February, March, … etc.) (i.e. calculate a Month Geo Mean).
7. The final monthly default ambient temperatures are the whole number rounded values of the Month Geo Means of "6.".
8. Repeat "4." - "7." for each of the separate classifications organized in "3.".

Hard copies of the data and analyses used to develop the default acute water quality criteria are provided in a red three-ring binder labeled "Ambient Temperature Development". Table 1 lists the complete set of monthly default ambient temperatures in the current rule.

Table 1. Monthly Default Ambient Temperatures for Different Wisconsin Water Body Uses and Communities

Month	Cold	Warm - Large	Warm - Small	LFF	N Inland Lakes	S Inland Lakes
January	35	33	33	37	35	35
February	36	33	34	39	34	39
March	39	36	38	43	35	41
April	47	46	48	50	41	49
May	56	60	58	59	55	58
June	62	71	66	64	67	70
July	64	75	69	69	72	77
August	63	74	67	68	71	76
September	57	65	60	63	63	67
October	49	52	50	55	52	54
November	41	39	40	46	43	42
December	37	33	35	40	35	35

Month	MS River	Rock River	Upper WI River	Lower WI River	Lower Fox River
January	32	33	33	32	35
February	33	35	33	32	35
March	36	38	35	37	38
April	47	49	44	48	50
May	60	64	60	61	62
June	72	71	70	71	73
July	76	74	75	75	77
August	76	73	73	74	76
September	67	66	65	67	68
October	54	54	51	53	53
November	40	40	39	40	42
December	33	34	33	33	35

Month	S Green Bay	N Green Bay	N Lake Michigan	S Lake Michigan	Lake Superior	Chequamegon Bay
January	35	35	34	35	35	35
February	35	35	33	34	34	35
March	41	36	35	37	34	35
April	47	40	39	43	35	38
May	56	48	44	48	41	50
June	66	57	48	54	49	59
July	70	62	53	59	55	62
August	70	64	56	63	57	64
September	65	61	53	60	57	60
October	54	54	48	53	50	49
November	39	44	42	45	43	39
December	37	37	36	38	38	35

Ta = ambient temperature **N** = northern **S** = southern
MS = Mississippi (River) **WI** = Wisconsin (River)

GENERAL INFORMATION REGARDING WATER QUALITY CRITERIA FOR TEMPERATURE

Two types of water quality criteria for temperature are proposed for each of the fish and aquatic life and water body uses listed earlier in this document (except for the limited aquatic life subcategory) - acute criteria and sub-lethal criteria. All criteria are developed based on a combination of factors to make them as relevant and specific to Wisconsin waters as possible, which together make them water quality-based (rather than categorical). The factors used to develop the criteria that make them water quality-based include:

criteria specific to each water body use or designation
used only data from fish species known to exist in Wisconsin
fish species data organized by specific water body use or designation
criteria related to ambient water temperatures in Wisconsin water bodies
ambient temperatures specific to each water body use or designation
life history activities considered for the months they are known to occur in Wisconsin

All acute and sub-lethal criteria are developed from fish-based data. This was done for two primary reasons. One is that there is far more temperature affects and related data available for fish species than for other organisms, such as aquatic plants, macroinvertebrates, and amphibians. It was determined that there was insufficient data from non-fish species to develop specific monthly acute and sub-lethal criteria. Two is that based on comparison with the limited data found for other organisms, it was determined that criteria based on fish species data would be protective of the aquatic environ as a whole. This assumption can be reassessed in the future if sufficient new temperature effects data is produced for non-fish species. However, data from aquatic plants, macroinvertebrates, turtles, amphibians, and zooplankton was used to establish a year-long criterion for limited aquatic life waters not categorized as wastewater effluent channels or wetlands regulated under NR 103.

As mentioned above, the acute and sub-lethal criteria "share" the same mixing zone, however each is applied differently within that mixing zone. The acute criteria are to be applied as daily maximum values. The sub-lethal criteria are to be applied as 7-day average of daily maximum values. As is discussed in greater detail in the "Chapter NR 106" section of this document, the water quality criteria are implemented within water quality-based effluent limitations. A calculated limitation represents the end-of-pipe effluent temperature that cannot be exceeded in order to assure the water quality criterion is met at the edge of the mixing zone. Please see the "Chapter NR 106" section of this document for further details.

Appendix 2 lists which fish species were used to develop the acute, maximum no spawning temperature, and maximum no growth temperature water quality criteria. This appendix includes one table for all waters except inland lakes, and one for northern and southern inland lakes. Each table includes a "classification" column that indicates which of the uses or communities listed on page 11 that the species belongs to. Some species have multiple uses or communities listed. This means that the species occurs in each of the uses or communities listed. Five species are listed as "cool" water species. This means that the species can occur in both cold and warm water uses. Some species are listed but are not used for developing any of the criteria, including any species classified as "extirpated/extinct" or "undesired exotic_". This simply means that data was available for these species, but was either an insufficient amount of data, or not relevant for developing criteria at this time. Appendix 3 specifies which of the six specific Great Lakes water classifications each of the Great Lakes species occur in.

DEFAULT ACUTE WATER QUALITY CRITERIA DEVELOPMENT

General

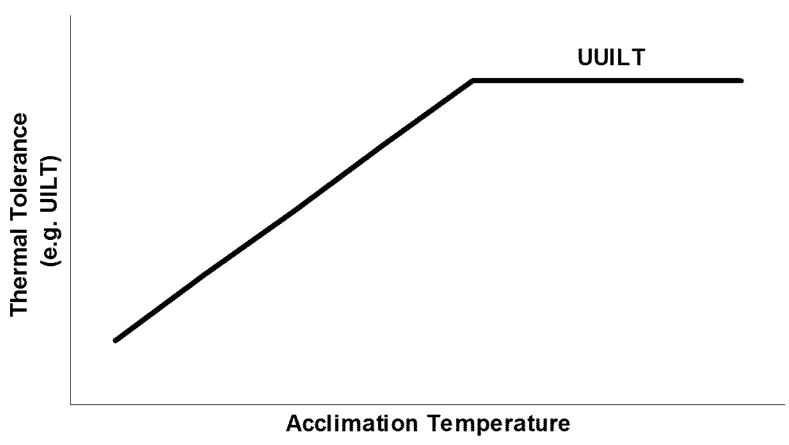
Acute water quality-based criteria for temperature represent maximum allowable temperatures that protect aquatic organisms from direct lethal affects of thermal loads at given ambient temperatures. Appropriate temperatures are essential for the quality and integrity of aquatic ecosystems, and aquatic organisms exist within particular temperature ranges, optimums, and tolerances. Additionally, metabolic limits and acclimation histories of different organisms ultimately determine their thermal tolerances. The acute criteria generation process is designed to account for these important factors.

Temperature tolerance and acclimation are two important concepts to consider when developing water quality-based acute criteria for temperature. Tolerance and acclimation to temperature are defined in Appendix 1 of this TSD. Generally, as acclimation temperatures increase, corresponding thermal tolerances also increase until they reach a maximum level (see Figure 1). This relationship forms the basis of the acute criteria generation process. For the purpose of establishing criteria, acclimation temperatures serve to approximate ambient water temperatures and the corresponding thermal tolerances approximate maximum allowable water temperatures.

The acute criteria are based on laboratory tests that use "doses" of temperature above a given acclimation temperature to observe a mortality-inducing response temperature. This is equivalent to dose-response toxicity testing for toxic substances. Specifically, the observed "response" measured in laboratory tests is the Upper Incipient Lethal Temperature (UILT). The UILT represents the temperature beyond which 50% of the test population acclimated at a given temperature can no longer survive an indefinite period of time (Giattinna and Garton 1982). The UILT is equivalent to an LC_{50} value, or in this case an LT_{50}. Since the LC50 assumes only 50% survival, the final acute criteria incorporate a "safety factor". A safety factor of a 3.6° F reduction of the UILT is designed to assure no deaths occur (Brungs and Jones 1977). Numerous studies have supported the assertions of the 3.6° F safety factor (Fry et al. 1942, Black 1953, Coutant 1970). Increasing the acclimation temperature provides a subsequent increase in thermal tolerance (e.g. UILT), but only to a point. This point is called the Ultimate Upper Incipient Lethal Temperature, or UUILT (see Figure 1). Essentially the UUILT represents the temperature at which an organism has exhausted its tolerance for increased heat loads, independent of acclimation history.

This approach allows for biologically appropriate "sliding scale" criteria by accounting for the ambient water temperature and acclimation history of the resident fish population. The "sliding scale" refers to the acclimation temperature - thermal tolerance relationship. It is the “sliding scale” nature of these criteria that help establish them as water quality-based, and which mark a major departure from the existing criteria for temperature, that do not fully consider water quality characteristics.

Figure 1. General Relationship of Thermal Tolerance, Acclimation Temperature, and the Ultimate Upper Incipient Lethal Temperature



Data

In order for data to be considered for analysis in the criteria generation procedure, it must include both the acclimation temperature and UILT, and comply with the standard methods for UILT testing found in Fry et al (1946) and McCauley (1981).* Information on acclimation times is optional, and requirements can vary from one week (Wismer and Christie 1987) to two or three weeks (Houston 1982). The data used to generate the proposed criteria meet these requirements, and new data incorporated into future revisions should also do so.

> * This includes the standard seven-day exposure period (McCauley, 1981). The basic procedure consists of initial acclimation of a sufficiently large population of fish which are subsequently transferred to a series of test temperatures, at which accumulative mortalities are recorded until a predetermined and sustained mortality level is reached. The resulting curves are then transformed to linear relationships using Probit (mortality) - logarithmic (time) transformations. These linearizations can give median resistance to mortality times at each test temperature, which are in turn used to estimate the lethal temperature (LT_{50} or UILT) tolerated by 50% of the test population (Houston 1982).

All data used in the development of the acute criteria are stored in a database, and each acclimation - UILT "pair" is assigned a unique identification number. All data entered into the database are printed in a hard copy "Acute Temperature Information" report. Both primary and compilation references for all acute data pairs are listed in the report. Due to the extensive size of the report (551 entries) and the reference list (81 entries), neither is included in this document. However, each is available upon request. Effort was made to assure that duplicate data was not used in the development of criteria. In all, 360 data pairs from a total of 38 different species were used to develop the water quality-based acute criteria (a summary is provided in Appendix 4).

Criteria Development

Default acute water quality criteria are developed according to the following steps:

1. Determine the list of fish species known to exist in Wisconsin.
2. Locate acclimation temperature - UILT data pairs for fish species in "1.".
3. Enter "2." into a database.
4. Organize the species and data in "3." into each of the non-LAL water body uses or communities listed on page 11.
5. Create a .txt file of the data, including as a minimum species, acclimation temperature, and UILT for each data pair, for each non-LAL water body uses or community.
6. Import the .txt file in "5." for all species with at least 4 acclimation temperature - UILT data pairs into SAS (or other statistical software program) and perform/calculate the following:
   a. Regressions for each species' set of data pairs, such that "y = mx + b" translates into "predicted UILT = slope x acclimation temperature + UILT at 32° F". For the development of criteria "acclimation temperature" is equivalent to ambient water temperature. Thus in the absence of actual laboratory-derived UILT at every potential ambient temperature, this approach uses the simple linear regression to develop a predictive relationship between ambient temperatures and UILT values for individual species. When appropriate, obvious outlier data pairs were removed from the data set, and the goal was to have species-specific r-squared values that exceeded 0.5. The majority of r-squared values were greater than 0.7.
   b. Analysis of covariance allowing for different slopes to test for different slopes among individual species slopes. This helps indicate that even if a common slope exists among all

individual species (see "c.") the thermal tolerances of all the individual fish species may vary widely and their responses to increasing temperatures cannot be easily or narrowly characterized.

c. Analysis of covariance for similar slopes to test for a common slope among all individual species slopes, which if supported, indicates a general relationship exists between increasing acclimation temperatures and corresponding UILT values for all the species within the given fish and aquatic life use.
d. Predict UILT at each acclimation temperature across a range of temperatures using the slopes and intercepts from "a." if common slopes are not support, or the common slope if it is supported in "c.".
e. Compute the mean UILT for each species at each temperature.
f. Compute the median mean UILT (from "e.") at each temperature.
g. Subtract the 3.6° F (2° C) safety factor from each median value from "f." at each temperature.
h. The final acute criteria are the whole number rounded values between the lowest acclimation temperature (in our case 32° F) and the temperature where the acclimation temperature and final acute criterion are equal.

7. Repeat "5." and "6." for each of the 17 non-LAL water body uses or communities listed on pages 11-12 that is home to a unique set of the species data has been collected for. For the current rule, 10 unique sets of acute criteria were developed - cold water, warm water (which includes large and small flowing waters and each of the 5 specific large rivers), limited forage fish water, northern inland lakes, southern inland lakes, southern Green Bay, northern Green Bay, Lake Michigan (which includes both southern and northern portions), Lake Superior, and Chequamegon Bay. Create a table that contains the acute criteria for each of the water uses, at each ambient temperature between 32° F and the maximum temperature from step "6.h". Table 2 lists the complete set of acute criteria for the current rule.
8. The final monthly default acute water quality criteria for each of the 17 non-LAL water body uses or communities listed on pages 11-12 are determined by finding the appropriate criterion in the table created in step "7." at each monthly ambient temperature (from Table 1 of the *Default Ambient Temperature Development* section above) for each water use. Table 7 lists the complete set of default acute water quality criteria in the current rule.

Hard copies of the data and analyses used to develop the default acute water quality criteria are provided in a red three-ring binder labeled "Thermal Criteria Development, Final, 4/2004". A visually-based explanation of how the acute criteria are developed is provided in Appendix 5. The SAS code used to develop the cold water acute water quality criteria is provided in Appendix 6 as an example.

Table 2. Final Acute Water Quality Criteria Across All Potential Ambient Temperatures

All Temperatures are in Degree Fahrenheit

	Inland Waters					Great Lakes Waters					
Ta [1]	Cold	Warm	LFF[2]	NIL [2]	SIL [2]	SGB [2]	NGB [2]	SLKMI [2]	NLKMI [2]	LKSUP [2]	CB [2]
32	68	75	77	75	76	74	69	69	69	68	68
33	68	76	77	76	76	74	69	69	69	69	69
34	68	76	77	76	76	75	69	69	69	69	69
35	68	76	77	76	77	75	69	69	69	69	69
36	68	76	78	76	77	75	70	69	69	69	69
37	69	77	78	77	77	75	70	70	70	69	69
38	69	77	78	77	77	76	70	70	70	69	69
39	69	77	79	77	78	76	71	70	70	70	70
40	69	77	79	77	78	76	71	70	70	70	70
41	69	78	79	78	78	77	71	70	70	70	70
42	69	78	79	78	78	77	71	70	70	70	70
43	69	78	80	78	78	77	71	70	70	70	70
44	70	78	80	78	79	78	71	71	71	71	71
45	70	79	80	79	79	78	71	71	71	71	71
46	70	79	80	79	79	78	72	72	72	71	71
47	70	79	81	79	80	79	72	72	72	71	71
48	70	79	81	79	80	79	72	72	72	72	72
49	70	79	81	80	80	79	73	72	72	72	72
50	70	80	81	80	80	79	73	73	73	72	72
51	71	80	82	80	81	80	73	73	73	72	72
52	71	80	82	80	81	80	73	73	73	72	72
53	71	80	82	81	81	80	74	73	73	72	72
54	71	81	82	81	81	80	74	73	73	73	73
55	71	81	83	81	82	81	74	73	73	73	73
56	72	81	83	81	82	81	75	73	73	73	73
57	72	82	83	82	82	81	75	73	73	73	73
58	72	82	83	82	82	81	75	74	74	73	73
59	72	82	84	83	83	81	76	74	74	74	74
60	72	82	84	83	83	82	76	74	74	74	74
61	72	83	84	83	83	82	77	75	75	74	74
62	72	83	84	83	84	82	77	75	75	75	75
63	73	83	85	84	84	82	78	76	76	75	75
64	73	84	85	84	85	82	78	77	77	76	76
65	73	84	85	84	85	83	78	77	77	76	76
66	73	84	85	85	85	83	79	78	78	77	77
67	74	84	86	85	85	83	79	78	78	77	77
68	74	85	86	85	85	83	80	79	79	78	78
69	74	85	86	85	86	83	80	79	79	78	78
70	74	85	86	86	86	83	81	80	80	79	79
71	74	85	87	86	86	84	81	81	81	79	79
72	75	85	87	86	86	84	82	81	81	80	80
73	75	85	87	86	86	84	82	82	82	80	80
74	75	86	87	86	87	84	82	82	82	81	81
75	75	86	88	87	87	85	83	83	83	81	81
76		86	88	87	87	85	83	83	83	82	82
77		87	88	87	87	85	84	84	84	83	83
78		87	88	87	88	86	84	84	84	83	83
79		87	89	88	88	86	84	84	84	83	83
80		87	89	88	88	86	84	84	84	83	83
81		88	89	88	88	86	84	84	84	83	83
82		88	89	88	89	87	84	84	84	84	84
83		88	90	89	89	87	84	84	84	84	84
84		88	90	89	89	88	85	85	85	84	84
85		89	90	89	89	88	85	85	85		
86		89	90	89	90	89					
87		89	91	90	90	89					
88		90	91	90	90	89					
89		90	91	90	91	89					
90		91	91	91	91						
91		91	92	91	92						
92			92		92						

[1] Ta = ambient temperature [2] See page 12 for definitions of all use classification acronyms in this table

DEFAULT SUB-LETHAL WATER QUALITY CRITERIA DEVELOPMENT

General

Sub-lethal water quality-based criteria for temperature represent maximum allowable temperatures that are generally protective of important life history activities of aquatic organisms from thermal loads. In particular, the sub-lethal criteria are based on data from three fish life history activities: gametogenesis, spawning, and growth. These three activities are vital to fish in particular, and in their equivalent forms to all aquatic organisms. For this reason it is important to assure that these activities are protected through criteria that specifically address them, and to not rely only on acute criteria to attempt to protect sub-lethal life history activities. Since sub-lethal effects generally occur over a much longer time frame than acute effects, the sub-lethal criteria are implemented as weekly averages, rather than daily maximums.

Unlike the acute criteria that are based on laboratory-derived data, the sub-lethal data is largely based on field-observed data, although some data is laboratory- or model-derived. In all, 614 references/sources of information were used in and support the development of the sub-lethal criteria. Additionally, there are currently no standardized methods for determining comprehensive, integrated sub-lethal thermal effects on fish or other aquatic organisms. Thus there is also no direct way to tie sub-lethal thermal effects with ambient temperature, as was done to develop the acute criteria. Additionally, there has not been any attempt to comprehensively gather temperature-related sub-lethal or life history data for all types of fish species across all types of water uses or communities for multiple life history activities in the State of Wisconsin (or in any other state to our knowledge).

Yet, sub-lethal criteria are considered water quality-based for many of the reasons listed in the "General Information Regarding Water Quality Criteria For Temperature" section above, including consideration only of fish species known to exist in Wisconsin, consideration of when the three life history activities occur in Wisconsin and when each species participates in each of the activities in Wisconsin, and development of criteria specific to each fish and aquatic life use. Further, through the methods discussed in the "*Final Sub-Lethal Criteria*" section below, the sub-lethal criteria developed here are intended to consider all three life history activities (i.e. criteria) as an interworking month-to-month continuum within each water use or community. Table 3 displays the months that each of the three life history activities the sub-lethal criteria are based on occur in Wisconsin within each water use or community.

Maximum Spawning Temperature Criteria

Default sub-lethal water quality criteria for maximum spawning temperature are developed according to the following steps:

1. Determine the list of fish species known to exist in Wisconsin (same as in acute section).
2. Locate spawning temperature data for fish species in "1." - the maximum temperatures of ranges will be used.
3. Determine when each of the species that data was found for in "2." spawns (see Appendix 7).
4. Enter "2." and "3." into a database.
5. Organize the species and maximum spawning temperature data in "4." into each of the non-LAL water body uses or communities listed on page 11.
6. Calculate the geometric mean of all maximum spawning temperature data in "5." for each species (i.e. calculate Species Geo Means) for a specific water use or community from pages 11-12.

7. Organize the species, maximum spawning temperature data, and Species Geo Means in "6." into the month(s) the species spawns in.
8. Calculate the geometric mean of all the Species Geo Means in "6." in each appropriate month using Table 3 and Appendix 8 (lists the general spawning areas/habits of fish species in Great Lakes waters of Wisconsin) as guides (i.e. calculate Month Group Geo Means).
9. The final monthly sub-lethal water quality criteria for maximum spawning temperature are the whole number rounded values of the Month Group Geo Means of "8.".
10. Repeat "6." through "9." for each of the 17 non-LAL water body uses or communities listed on pages 11-12 that is home to a unique set of the species data has been collected for. For the current rule, 11 unique sets of maximum spawning temperature criteria were developed - cold water, warm water (which includes large and small flowing waters and each of the 5 specific large rivers), limited forage fish water, northern inland lakes, southern inland lakes, southern Green Bay, northern Green Bay, northern Lake Michigan, southern Lake Michigan, Lake Superior, and Chequamegon Bay. Table 4 lists the complete set of maximum spawning temperature criteria in the current rule.

All data used in the development of the sub-lethal water quality criteria for maximum spawning temperature are stored in a database, and each maximum temperature entry is assigned a unique identification number. All data entered into the database are printed in a hard copy "Spawning Temperature Information" report. Both primary and compilation references for all spawning data are listed in the report. Due to the extensive size of the report (510 entries) and the reference list (496 entries), neither is included in this document. However, each is available upon request. Effort was made to assure that duplicate data was not used in the development of criteria. Hard copies of the data and analyses used to develop the default sub-lethal criteria for maximum spawning temperature are provided in a red three-ring binder labeled "Thermal Criteria Development, Final, 4/2004". In all, 338 maximum spawning temperature data points from a total of 113 different species were used to develop the sub-lethal criteria for maximum spawning temperature (a summary is provided in Appendix 9).

Table 3. Life History Activity Occurrence in Different Wisconsin Water Body Types

	COLD	WARM	LFF	SGB	GL Waters Except SGB	Inland Lakes
January	S	GM	GM	GM	GM / S	GM
February	S	GM	GM	GM	GM / S	GM
March	S	GM / S	GM / S	GM / S	GM / S	GM / S
April	S	S	S	S	S	S
May	S / GR	S	S	S	S	S
June	S / GR	S	S	S	S	S
July	GM	S / GR	S / GR	S / GR	S / GR	S / GR
August	GM	S / GR	S / GR	S / GR	S / GR	S / GR
September	S / GM	GR	GR	GR	GR	GR
October	S	GM	GM	S	S	GM
November	S	GM	GM	S	S	GM
December	S	GM	GM	S	S	GM

GM = gametogenesis occurs, use the gametogenesis criterion
S = spawning occurs, use the maximum spawning temperature criterion
GR = general period of growth occurs, use the maximum no-growth temperature criterion
When two life history activities occur in the same month, use the more conservative criterion.
See page 12 for definitions of all use classification acronyms in this table.

Table 4. Final Sub-Lethal Water Quality Criteria for Maximum Spawning Temperature

	Water Use Classification										
				Great Lakes Waters							
Month	**Cold**	**Warm**	**LFF**	**SGB**	**NGB**	**NLKMI**	**SLKMI**	**LK SUP**	**CB**	**NIL**	**SIL**
January	47				44	44	44	42	42		
February	45				43	43	43	43	43		
March	53	59	64	59	54	54	52	52	52	58	62
April	59	65	64	60	59	60	61	58	58	63	64
May	59	70	75	66	64	65	67	65	65	70	70
June	67	72	75	70	67	67	68	67	67	72	72
July		74	75	70	68	68	68	69	69	75	74
August		78	77	71	67	67	67	69	69	77	77
September	52										
October	52			50	50	50	50	45	54		
November	50			47	47	47	47	44	46		
December	46			47	45	45	45	43	44		

All criteria (temperatures) are in degree Fahrenheit.
See page 12 for definitions of all use classification acronyms in this table.

The final sub-lethal water quality criteria for maximum spawning temperature listed in Table4 are inputs for determining the final sub-lethal criteria, as described below.

Maximum No Growth Temperature Criteria

Default sub-lethal water quality criteria for maximum no growth temperature are developed according to the following steps:

1. Determine the list of fish species known to exist in Wisconsin (same as in acute section).
2. Locate no growth temperature data for fish species in "1." - the maximum temperatures of ranges will be used.
3. Enter "2." into a database.
4. Calculate the geometric mean of all maximum no growth temperature data in "3." for each species (i.e. calculate Species Geo Means - see Appendix 10).
5. Organize the species, Species Geo Means, and other information in "3." and "4." into each of the non-LAL water body uses or communities listed on page 11.
6. Calculate the geometric mean of all the Species Geo Means in "5." for each use or community (i.e. calculate Classification Geo Means).
7. The final monthly sub-lethal water quality criteria for maximum no growth temperature are the whole number rounded values of the Classification Geo Means of "6.".
8. Repeat "6." and "7." for each of the 17 non-LAL water body uses or communities listed on pages 11-12 that is home to a unique set of the species data has been collected for. For the current rule, 11 unique sets of maximum no growth temperature criteria were developed - cold water, warm water (which includes large and small flowing waters and each of the 5 specific large rivers), limited forage fish water, northern inland lakes, southern inland lakes, southern Green Bay, northern Green Bay, northern Lake Michigan, southern Lake Michigan, Lake Superior, and Chequamegon Bay. Table 5 lists the complete set of maximum no growth temperature criteria in the current rule.

All data used in the development of the sub-lethal water quality criteria for maximum no growth temperature are stored in a database, and each maximum temperature entry is assigned a unique identification number.

All data entered into the database are printed in a hard copy "Growth Temperature Information" report. Both primary and compilation references for all growth data are listed in the report. Due to the extensive size of the report (350 entries) and the reference list (139 entries), neither is included in this document. However, each is available upon request. Effort was made to assure that duplicate data was not used in the development of criteria. Hard copies of the data and analyses used to develop the default sub-lethal criteria for maximum no growth temperature are provided in a red three-ring binder labeled "Thermal Criteria Development, Final, 4/2004". In all, 124 maximum no growth temperature data points from a total of 27 different species were used to develop the sub-lethal criteria for maximum no growth temperature (a summary is provided in Appendix 10).

Table 5. Final Sub-Lethal Water Quality Criteria for Maximum No Growth Temperature

Water Use Classification	Final Criterion (degree Fahrenheit)
Cold	72
Warm	87
LFF	92
Northern Inland Lakes	87
Southern Inland Lakes	87
Southern Green Bay	83
Northern Green Bay	79
Northern Lake Michigan	79
Southern Lake Michigan	79
Lake Superior	79
Chequamegon Bay	79

The final sub-lethal water quality criteria for maximum no growth temperature listed in Table 5 are inputs for determining the final sub-lethal criteria, as described below.

Maximum Gametogenesis Temperature Criteria

Since far fewer data was available for the development of sub-lethal water quality criteria for maximum gametogenesis temperature, best professional judgment was the primary means for determining the final criteria. In all, 12 maximum gametogenesis temperature data points from a total of 7 different species were used to develop the sub-lethal criteria for maximum gametogenesis temperature (the data used is provided in Appendix 11). These data came from two references/sources of information. The selection of temperatures was aided by considering when gametogenesis occurs in Wisconsin, as provided in Table 3. The following are the primary decisions made in finalizing the maximum gametogenesis temperature criteria:

1. Since gametogenesis for cold water species occurs during the summer months in Wisconsin (see Table 3) the most common summer temperature value recorded (68° F) was used.
2. The use of 50° F, 50° F, and 54° F for January, February, and March, respectively, and 54° F, 50° F, and 50° F for October, November, and December, respectively, for the warm water and Great Lakes fish and aquatic life use communities is based on 50° F being appropriate for winter and 54° F being appropriate during longer days (for late fall or early spring spawners).
3. The use of 54° F for the limited forage fish community is based on the data for white sucker, the only species with gametogenesis temperature data that is in the limited forage fish community.

Table 6. Final Sub-Lethal Water Quality Criteria for Maximum Gametogenesis Temperature

	Water Use Classification					
Month	**Cold**	**Warm**	**LFF**	**Great Lakes**	**NIL**	**SIL**
January		50	54	50	50	50
February		50	54	50	50	50
March		54	54	54	54	54
April						
May						
June						
July	68					
August	68					
September	68					
October		54	54		54	54
November		50	54		50	50
December		50	54		50	50

All criteria (temperatures) are in degree Fahrenheit.
See page 12 for definitions of all use classification acronyms in this table.

The final sub-lethal water quality criteria for maximum gametogenesis temperature listed in Table 6 are inputs for determining the final sub-lethal criteria, as described below.

Final Default Sub-Lethal Criteria

The tables, graph, and other information in Appendix 12 are visual examples of the explanations in this section.

The first step in the development of the final default sub-lethal criteria is to organize each of the sub-lethal criteria for maximum spawning temperature, maximum no growth temperature, and maximum gametogenesis temperature, as developed according to the above sections, by each of the 17 non-LAL water body uses or communities listed on pages 11-12 and by month, using Table 3 as a guide. As mentioned above, when two life history activities occur in the same month, the more conservative criterion is used. Thus one sub-lethal criterion should remain for each month.

Compare the sub-lethal criterion for each month with the default ambient temperature and associated default acute water quality criterion (as developed according to the sections above) for the same months. Two "common sense" problems may occur. One is when the sub-lethal criterion is less than the ambient temperature for a given month. The other is when the sub-lethal criterion is greater than the acute criterion for a given month. The following are two precedented methods for addressing these "common sense" problems:

- When the sub-lethal criterion is less than the ambient temperature in a given month, the ambient temperature becomes the final sub-lethal criterion for that month.
- When the sub-lethal criterion is greater than the acute criterion in a given month, the final sub-lethal criterion for that month equals the acute criterion

The outcome of these sub-lethal criteria, following any adjustments, are the prefinal sub-lethal thermal water quality criteria - developed for each month and non-LAL water body use or community.

The final step in the development of the final default sub-lethal criteria is to apply a five factor polynomial regression of the prefinal sub-lethal criteria for each non-LAL water body use or community. Using the equation generated from the five factor polynomial regression, the final sub-lethal thermal water quality criteria can be calculated and presented as rounded whole number values.

The final sub-lethal thermal water quality criteria were determined/calculated as described above except as follows:

U.S. EPA Region 5 conducted a review of WDNR's data on maximum fish spawning temperatures in the draft TSD and noted that WDNR's proposed sub-lethal criteria for warm waters did not appear to be protective of spawning requirements for some (essentially “cool” water) fish species. To address this concern the calculated final sub-lethal thermal water quality criteria for warm water during the months of February, March, April, and May were revised from 52, 55, 61, and 68 degrees Fahrenheit to 50, 52, 55, and 65 degrees Fahrenheit, respectively. This includes the criteria for all five specific large warm water rivers.

For example, for the sauger the geometric mean maximum spawning temperature based upon data used by WDNR was 53.4 F, and the proposed criteria during the spawning months for this species were 61 in April and 68 in May. Thus, the criteria were changed to 55 and 65 degrees for these two months, respectively, to provide one month (April) when the sub-lethal criterion will be close to the maximum spawning temperature for sauger. The revised temperatures will also ensure the protection of spawning requirements for other species with similar requirements.

Table 7 lists the final set of monthly default ambient temperatures, sub-lethal water quality criteria, and acute water quality criteria for all 17 non-LAL water body uses or communities listed on pages 11-12.

Table 7. Monthly Default Ambient Temperatures & Water Quality Criteria for Different Wisconsin Water Body Uses

	Cold			Warm - Large			Warm - Small			LFF			N Inland Lakes			S Inland Lakes		
Month	Ta	S-L	AC	Ta	S-L	AC	Ta	S-L	AC	Ta	S-L	AC	Ta	S-L	AC	Ta	S-L	AC
January	35	47	68	33	49	76	33	49	76	37	54	78	35	49	76	35	49	77
February	36	47	68	33	50	76	34	50	76	39	54	79	34	52	76	39	52	78
March	39	51	69	36	52	76	38	52	77	43	57	80	35	55	76	41	55	78
April	47	57	70	46	55	79	48	55	79	50	63	81	41	60	78	49	60	80
May	56	63	72	60	65	82	58	65	82	59	70	84	55	67	81	58	68	82
June	62	67	72	71	75	85	66	75	84	64	77	85	67	75	85	70	75	86
July	64	67	73	75	80	86	69	79	85	69	81	86	72	79	86	77	80	87
August	63	65	73	74	79	86	67	78	84	68	79	86	71	79	86	76	80	87
September	57	60	72	65	72	84	60	72	82	63	73	85	63	72	84	67	73	85
October	49	53	70	52	61	80	50	61	80	55	63	83	52	61	80	54	61	81
November	41	48	69	39	50	77	40	50	77	46	54	80	43	50	78	42	50	78
December	37	47	69	33	49	76	35	49	76	40	54	79	35	49	76	35	49	77

	MS River			Rock River			Upper WI River			Lower WI River			Lower Fox River		
Month	Ta	S-L	AC	Ta	S-L	AC	Ta	S-L	AC	Ta	S-L	AC	Ta	S-L	AC
January	32	49	75	33	49	76	33	49	76	32	49	75	35	49	76
February	33	50	76	35	50	76	33	50	76	32	50	75	35	50	76
March	36	52	76	38	52	77	35	52	76	37	52	77	38	52	77
April	47	55	79	49	55	79	44	55	78	48	55	79	50	55	80
May	60	65	82	64	65	84	60	65	82	61	65	83	62	65	83
June	72	75	85	71	75	85	70	75	85	71	75	85	73	76	85
July	76	80	86	74	79	86	75	80	86	75	80	86	77	81	87
August	76	79	86	73	79	85	73	79	85	74	79	86	76	80	86
September	67	73	84	66	72	84	65	72	84	67	72	84	68	73	85
October	54	61	81	54	61	81	51	61	80	53	61	80	53	61	80
November	40	50	77	40	50	77	39	50	77	40	50	77	42	50	78
December	33	49	76	34	49	76	33	49	76	33	49	76	35	49	76

	S Green Bay			N Green Bay			N Lake Michigan			S Lake Michigan			Lake Superior			Chequamegon Bay		
Month	Ta	S-L	AC	Ta	S-L	AC	Ta	S-L	AC	Ta	S-L	AC	Ta	S-L	AC	Ta	S-L	AC
January	35	49	75	35	43	69	34	43	69	35	43	69	35	41	69	35	41	69
February	35	52	75	35	47	69	33	47	69	34	46	69	34	46	69	35	46	69
March	41	54	77	36	52	70	35	52	69	37	52	70	34	51	69	35	51	69
April	47	58	79	40	57	71	39	58	70	43	59	70	35	57	69	38	57	69
May	56	64	81	48	63	72	44	64	71	48	65	72	41	63	70	50	63	72
June	66	70	83	57	68	75	48	69	72	54	70	73	49	69	72	59	69	74
July	70	75	83	62	71	77	53	71	73	59	71	74	55	72	73	62	72	75
August	70	75	83	64	71	78	56	69	73	63	70	76	57	71	73	64	71	76
September	65	70	83	61	66	77	53	64	73	60	64	74	57	64	73	60	66	74
October	54	60	80	54	58	74	48	55	72	53	57	73	50	55	72	49	57	72
November	39	49	76	44	49	71	42	47	70	45	49	71	43	45	70	39	48	70
December	37	46	75	37	44	70	36	44	69	38	44	70	38	42	69	35	43	69

Ta = ambient temperature **S-L** = sub-lethal criteria **AC** = acute criteria

N = northern **S** = southern

Acute criteria are implemented as daily maximum values.
Sub-lethal criteria are implemented as 7-day average values.
The acute criterion will always be underlying the sub-lethal criterion.

SITE-SPECIFIC OPTIONS

Since the steps necessary for developing site-specific ambient temperatures and site-specific water quality criteria for temperature are listed in the rule language (NR 102.26 and 102.27), they will not be repeated in this document. However, what is provided below are explanations of some of the steps presented in the rule.

Site-Specific Ambient Temperature Development

The purpose of showing the data used to derive the default ambient temperatures (as discussed above) do not apply to the specific water segment or body in question is to build a reasoned case for the need or desire to develop site-specific ambient temperatures.

The allowance to use data collected any time after October 1987 is provided as one way to keep the site-specific approach equivalent with the default approach, as discussed above.

Monthly data sets that are missing limited amounts of data (i.e. ≤ 10 missing days in the months of December, January, and February or ≤ 5 missing days per month in the months of March through November) can be used for developing ambient temperatures to avoid not using useful data, when data may be limited. Allowing up to five days of missing data is fine for most months because it does not alter the monthly average in an appreciable manner. Allowing up to ten days of missing data is fine for the months of December through February because the water temperature varies so little, that even ten days of missing data does not alter the monthly average in an appreciable manner.

A minimum of 2 or 3 years worth of data is required in efforts to collect the most representative ambient temperature data possible. Requiring just one year of data may lead to data being collected in a particularly (and abnormally) warm or cold year that is not representative of the normal condition.

Using Site-Specific Ambient Temperatures to Establish Water Quality Criteria

The procedures used for establishing acute and sub-lethal water quality criteria when using site-specific ambient temperatures are equivalent to those used to develop default acute and sub-lethal water quality criteria (as described above).

Table 6 in NR 102 is the same as Table 2 in this document. Table 7 in NR 102 is simply the overlay of Tables 4, 5, and 6 with Table 3 (all of this document), using the most conservative (lower) temperature if two temperatures are given for any month - water use or community combination.

Site-Specific Water Quality Criteria Development

Site-specific water quality criteria for temperature are to be used for a specific water segment or body.

The same methods used to develop the default water quality criteria for temperature may be used to develop site-specific criteria, the only difference being the species assemblage for the site-specific criteria will differ from that used for the default criteria. Alternatively, an entirely different method may be used to develop site-specific criteria. The alternative method must be protective of the fish and other aquatic life community in the specific water segment or body, at both the acute and sub-lethal levels. Further, the department must approve the alternative method.

Site-specific water quality criteria for temperature must be promulgated before they can be applied on a site-specific basis.

TEMPERATURE CRITERIA FOR PUBLIC HEALTH & WELFARE

A temperature criterion for the protection of public health and welfare is designed to protect humans from scalding. The criterion of 120°F is based on information gathered from nine sources. The following information comes from existing codes or recommendations aimed at protecting humans from heated water:

Temperature (degree F)	Limit/Standard/Recommendation
100	Recommended "safe temperature for bathing children" [Safe Kids Canada]
104	Maximum water temperature of a public whirlpool [WI Comm 90.19(7)]
104	Maximum water temperature of a public whirlpool [WI HFS 172.10(2)(b)]
106	Maximum water temperature at shower & washbasin outlet [UK Health & Safety Executive LAC # 79/5]
110	Maximum water temperature at fixtures in showers & tubs [WI HFS 83.41(5)(d)2]
110	Maximum water temperature at plumbing fixtures used by residents [WI HFS 132.83(7)(a)2]
110 - 120	Recommended maximum temperature at plumbing fixtures used by residents [WI HFS (DSL-BQA 98-021)]
111	Maximum water temperature at bath outlet [UK Health & Safety Executive LAC # 79/5]

Safe Kids Canada = advocacy for safe tap water regulation in Canada
WI Comm = Wisconsin Department of Commerce
WI HFS = Wisconsin Department of Health and Family Services
UK Health & Safety Executive LAC = United Kingdom Health & Safety Executive Local Authority Circular

Based on this information, it was determined that the final criterion should be between 110° and 120°F. To determine exactly what the criterion would be, the following information was used:

Temperature (degree F)	Time to Cause a "Bad" (2nd or 3rd Degree) Hot Water Burn
110	13 minutes
120	10 minutes
127	1 minute
130	10 - 30 seconds
140	1 - 6 seconds

Sources: = Wisconsin Department of Health and Family Services (DSL-BQA 98-021), Drs. Moritz and Henriques (from Safe Kids Canada website), University of Michigan Health System "Burn Safety: Hot Water Temperature" website

It was determined that 120°F would be the most appropriate criterion to protect against human scalding. The major drop in time to cause second or third degree burning from hot water occurred after 120°F, not after 110 °F. And ten minutes seemed a safer option than 1 minute (if the criterion was increased to 127°F). Additionally, the 110°F WI HFS limits are for situations of constricted, small-area, direct human contact scenarios. Other considerations such as the fact that discharges would be into surface waters which would cool with distance from the discharge, many discharges of heated water would be into flowing waters that would increase mixing and speed of heat dissipation, and that people would most likely not be submerged in the direct and unmixed effluent all weighed in the decision to make the criterion 120°F.

The 120°F criterion for protection of public health and welfare applies to all surface waters of the State.

TEMPERATURE CRITERIA FOR LIMITED AQUATIC LIFE WATERS

Types of Limited Aquatic Life Waters

Chapter 104, Wisconsin Administrative Code, lists and defines six surface water types (or hydrologic classifications) and specifically defines which of these water types may be or are to be applied as Limited Aquatic Life (LAL) waters (a fish and aquatic life use defined in NR 102, Wisconsin Administrative Code). One of the six water types is unique from the others as it is the only one that "includes discharge conveyances constructed primarily for the purpose of transporting wastes from a facility to a point of discharge", where as the others largely define more natural situations. This unique classification is titled "wastewater effluent channels". Since it is highly modified or man-made for specific effluent purposes it is treated differently than the other classifications in terms of thermal criteria.

Water Quality Criteria and Effluent Limitations for Limited Aquatic Life Waters

Water Quality Criteria:

- 86°F for LAL waters that are not wastewater effluent channels or wetlands regulated under ch. NR 103 (proposed in NR 102.24(3)(b))
- 120°F for protection of public health and welfare (proposed in NR 102.04(8)(c))
- 120°F for LAL waters that are wastewater effluent channels (proposed in NR 102.24(3)(c)) – thus this criterion is to be protective of public health and welfare

Effluent limitations for LAL waters:

- 86°F instantaneous maximum limitation for LAL waters that are not wastewater effluent channels or wetlands regulated under ch. NR 103 (proposed in NR 106.55(2))
- 120°F instantaneous maximum limitation for LAL waters that are wastewater effluent channels (proposed in NR 106.55(3))
- Limitations shall be established for wetlands on a case-by-case basis to meet water quality standards provided in NR 103 (proposed in NR 106.55(4))

Table 8 summarizes the water quality criteria and limitations for LAL waters:

Table 8. Summary of Water Quality Criteria and Effluent Limitations for LAL Waters

Hydrologic Classification	LAL ?	Water Quality Criteria	Effluent Limitation
Lakes & Flowages	Case-by-Case	LAL = 86° F Other = *1	LAL = 86° F Other = WQBEL *2 or 120° F
Diffused Surface Waters	Yes	86° F	86° F
Wetlands	Yes	*3	*4
Wastewater Effluent Channels	Yes	120° F	120° F
Noncontinuous Streams	May be	LAL = 86° F Other = *1	LAL = 86° F Other = WQBEL *2 or 120° F
Continuous Streams	May be	LAL = 86° F Other = *1	LAL = 86° F Other = WQBEL *2 or 120° F

*1 = acute and sub-lethal monthly water quality criteria or 120° F
*2 = WQBEL = Water Quality-Based Effluent Limitation
*3 = established/Regulated under ch. NR 103
*4 = established on a case-by-case basis to meet the water quality standards provided in NR 103

Support of the 86 °F Criterion and Effluent Limit for Limited Aquatic Life Waters

Note the following:

°C	=	°F
15		59
20		68
25		77
30		86
35		95
40		104
45		113

The following comes from or is supported by thirteen sources of information provided in the reference section of this document:

General Comments:

- 120°F (as previously proposed) is not biologically or ecologically protective … common sense.
- These water bodies are not “waste” areas – they are often valuable natural communities.
- Often these water bodies have very low or no flow, and thus have essentially no assimilative capacity to “absorb” heat.

Comments about the effects of temperature on freshwater algae:

- In fresh water the optimum temperature for the great majority of algae lies between 10–15 and 20-25 °C (Prescott, 1968, pg. 285).

- If temperatures are increased from 10 to 38°C, the predominant species groups change correspondingly from diatoms to green algae to blue-green algae. (Wallace, 1955)
- Blue-green algae species take over at temperatures greater than 95°F (Cairns, 1956; Patrick, 1969, pp. 167, 181-182). Blue-green algae are a noted public and pet health issue (Harrahy, 2007 and Imlay, 1969), and are a much poorer food source for natural aquatic communities. (Harrahy, 2007 and Patrick, 1969, p. 182)
- Extremes of temperature exert a selectivity of [algal] species and determine which ones can or cannot exist in a particular habitat or area (Prescott, 1968, p. 285).

Comments about the effects of temperature on freshwater algae from Ruth Patrick (1969):

- By far the largest number of species of algae are those that live at intermediate temperatures [like those in Wisconsin]. The group of species which live in these intermediate temperature ranges are by far the most important to the ecosystem of the fresh waters. (pp. 166-167)
- In an experiment started with river water at 18-20°C and the temperature gradually warmed to 40°C, the following were observed: Between the temperatures of 20–30°C diatoms were the dominant species, between the temperatures of 30-35° C green algae became dominant, and above 35° C blue-green algae were dominant. When the temperatures were gradually lowered, the green algae and diatoms reappeared at their respective temperature ranges. This indicated that all of the organisms of a given group were not killed when its optimum range was exceeded, but the species were not able to compete successfully with those species better suited to a given temperature range. (pp. 166-167)
- In general, the blue-green algae have more species that prefer temperatures from 35°C upward, whereas the green algae have a relatively large number of species that grow best in temperatures ranging up to 35°C, although some can grow at higher temperatures. Most of the diatoms prefer temperatures below 30°C. (pp. 181-182)
- The evidence we have indicates that when the temperatures rise above 35° C blue-green algae often become dominant, if this high temperature is maintained for fairly long periods of time. Since these algae are a poor food source, the ecosystem may be severely damaged. (p. 182)
- In another experiment, increasing temperatures over the naturally occurring temperature increased the biomass until temperatures of 29-30°C were reached. At 30°C and 33.8°C, there was a decided decrease in biomass.
- The natural seasonal succession of species which we find is largely due to the fact that species can out-compete each other under varying temperature conditions. Of course, other ecological conditions (such as light and nutrients) also control the kinds of species which we find at various seasons of the year. (p. 182)
- Studies made concerning the effect on algae of passing them through a condenser indicate that if the temperature does not exceed 34-34.5°C, little, if any, harm is done. (p. 182)

General biological and ecological aspects of amphibians and turtles as they relate to temperature and LAL environments:

- The young of all Wisconsin amphibians hatch from eggs and all but one species begins its life in water as larvae. Eggs and larvae are most sensitive to the effects of habitat degradation, making good water quality particularly important to their survival. (Christoffel, et al, 2001, p. 2)
- Frog breeding generally begins during three relatively discreet times for different species. These occur in early spring, late spring, and summer, each corresponding to a water temperature of approximately 50°F, 60°F, and 70°F, respectively. (Christoffel, et al, 2001, p. 5)
- According to a figure in Christoffel, et al, 2001, p. 5, all Wisconsin frog species and five of seven salamander species breed between mid-March and early August. Four salamander species breed

between September and November. These include one endangered species, two species of Special Concern, and three species with declining to significantly declining populations. (Christoffel, et al, 2001)

- Mid-March through August is a critical time for amphibians – and 95°F would be much preferred rather than 120°F for these times. (Bob Hay, 2007)
- Wetland habitats used by the early spring breeders are often temporary (ephemeral) ponds that have been created by snowmelt and spring rains [the definition of "diffused surface waters]. These habitats greatly increase production because they do not support fish, which are major predators of amphibian eggs and larvae. (Christoffel, et al, 2001, p. 6)
- Late spring breeding amphibians are also most productive in semi-permanent wetlands that are fishless. (Christoffel, et al, 2001, p. 6)
- The thin, permeable skin of amphibians allows for the absorption and release of water. Chemicals in their aquatic environments permeate the skin and can result in developmental problems and death. (Christoffel, et al, 2001, p. 8)
- A few species, like spring peepers and wood frogs, freeze solid during the winter. (Christoffel, et al, 2001, p. 11)
- Amphibians play very important roles in the natural communities where they live. (Christoffel, et al, 2001, p. 13-14 lists several of these)
- Ten of Wisconsin's eleven turtle species spend the winter under water. (Christoffel, et al, 2002, p. 10)
- The Blanding's Turtle, a threatened species, prefers shallow marshy habitats with abundant submerged vegetation, although they can be found in almost any aquatic habitat. They are semi-terrestrial and often move between wetlands during the active season. (Christoffel, et al, 2002, p. 31)
- Marshes and ponds are two of the preferred habitats of Western Painted Turtles (Christoffel, et al, 2002, p. 33)
- Twenty-seven temperate anurans (frogs) acclimated to 5°C for 2-3 weeks had an average critical thermal maximum of 32.6°C. Fifteen temperate anurans (frogs) acclimated to 23°C for 2-3 weeks had an average critical thermal maximum of 35.3°C. Eighteen temperate anurans (frogs) acclimated to 30°C for 2-3 weeks had an average critical thermal maximum of 34.3°C. The critical thermal maximum threshold was determined by the onset of spasms. (Brattstrom, 1968)
- The highest temperature tolerated (the temperature lethal to 50% of the sample) in Alaska is 36°C. (Herreid and Kinney, 1967)
- *Rana pipiens* (northern leopard frog) larvae do not have the ability to acclimate metabolically to large increases in heat. (Parker, 1967)

Much of the non-fish data the original Advisory Committee gathered in 1995 has 35° C (95° F) as a high tolerance or approximate lethal value (Thermal Standards TAC Meeting Minutes, June 14, 1995):

- The upper lethal temperature estimates for zooplankton are generally in the 35-45°C (95-113°F) range.
- Lethal temperatures limits for aquatic insects can vary widely. For instance, stoneflies are probably one of the least temperature tolerant aquatic insects, yet thermal tolerances range from 13-27°C. Mayflies and caddisflies are generally more tolerant, with upper limiting temperature tolerances ranging from 20-25°C to 25-35°C.
- Mussels and snails best tolerate temperatures of 22°C or less. However, temperature is less a concern for these organisms than is oxygen availability. Where temperature is a concern, it is because of the dissolved oxygen-temperature association.

RELATED STANDARDS

Cold Shock Standard

This is a narrative standard intended to prevent cold shock impacts to fish and other aquatic life communities. Cold shock is the exposure of aquatic organisms to a rapid decrease in temperature and a sustained exposure to a low temperature that induces abnormal behavioral or physiological performance and often leads to death. Heated discharges to confined, narrow, and/or small areas during cold months present the greatest risk. An example is a heated discharge to a long, narrow channel during winter. Another example would be a heated discharge to an enclosed harbor during January. Operational changes to heated discharges in high risk environments should estimate the potential for cold shock. Examples of such operational changes include power plant shut downs for maintenance, and decreases in heated effluent from manufacturing facilities during lull periods. Emergency shut downs are not held to this standard, however, all efforts should be made through general operational planning to avoid an emergency action that would cause cold shock.

Rate of Temperature Change Standard

This is a narrative standard intended to prevent deleterious effects from rapidly changing water temperatures to fish and other aquatic life communities. There is no specific rate of temperature change (degrees Fahrenheit per unit of time) that is listed in the rule. Additionally, the rule does not make any mention of specific patterns of temperature change that are acceptable or unacceptable (such as increasing, decreasing, or a series of increasing and decreasing). The reason the rule is not more specific in these areas is because it would be very difficult, if not impossible, to develop specific language and values that would be practical across a wide range of scenarios. Best professional judgment should be used to address rate of temperature change issues. Discharges from dams, detention or retention ponds, and industrial operations with variable discharge temperatures present the greatest risks for rate of temperature change problems. The single greatest concern is for relatively warm water to be discharged to cold water bodies.

CHAPTER NR 106

NOTE: Being a Technical Support Document, this document provides *technical* details, information, and references that supports thermal rule language, and is not intended to provide details and guidance regarding how the thermal rules are to be implemented. A separate Thermal Rule Implementation Guide is provided to cover these details.

OVERVIEW OF REVISIONS AND ADDITIONS

The primary revisions proposed for Chapter NR 106 include the following:

- Renaming of the chapter title
- Development of an entirely new Subchapter (Subchapter V) to specify how the Department will calculate water quality-based effluent limitations (WQBELs) under s. 283.13(5), Stats., for temperature and to specify how the Department will determine when such limitations will be included in Wisconsin Pollution Discharge Elimination System (WPDES) permits for the protection of Wisconsin's waterways.
- Development of an entirely new Subchapter (Subchapter VI) to establish procedures for the determination of alternative thermal effluent limitations as authorized under s. 283.17, Stats. This subchapter replaces NR 209 and is the state equivalent of federal 316(a).

WQBELs for temperature and heated discharges are needed to assure the attainment and maintenance of thermal surface water quality standards in Chapter NR 102.

It is important to remember that Chapter NR 106, and thus also the new thermal subchapters, pertain to point source discharges only. Additionally, remember that the basis for much of Subchapters V and VI is the fact that heat is a nonconservative/dissipating pollutant. Thus, a mixing zone within the receiving water is allowed when considering WQBELs for temperature.

GENERAL

Water quality-based effluent limits (WQBELs) in WPDES permits provide a mechanism to meet water quality criteria for all types of receiving waters. For discharges of toxic substances, acute criteria are met within a short distance of the point of discharge, while chronic criteria are met at the edge of a larger designated mixing zone. However, heat, unlike most toxic substances, is generally rapidly and continuously lost to the surrounding environment. Thus this rule applies both the acute and sub-lethal temperature criteria at the edge of a mixing zone. This is appropriate because:

- The dissipative characteristic of heated discharges contrasts with the behavior and fate of most toxic substances.
- Most fish and other aquatic life exhibit behavioral thermoregulation, and can avoid potentially lethal temperatures around the discharge location (as is similar with some toxic substances). Note however that some aquatic life, such as plankton or rooted plants, do not have the ability to avoid thermal plumes.
- There are valid technical considerations and siting constraints that require some facilities to discharge heat. Therefore, there is a practical need in some cases to permit dischargers to use a portion of the receiving water as a heat sink, while not allowing significant environmental impact.

- Regardless of any aspect of NR 106, s. NR 102.05(3) defines acceptable mixing zone considerations that are to be followed, including: mixing zones should be as small as practicably possible, allow for free passage of fish and other mobile aquatic organisms, and not interfere with spawning and nursery areas or migratory routes. Additionally, mixing zones in unidirectionally flowing waterbodies should be no larger than 1/4 of the cross sectional area or no wider than 1/2 the stream width. In an effort to meet these requirements, 1/4 of the appropriate stream flow is generally used in making calculations that take into account the dilution capacity of the receiving water. Based on the statistical probability of exceeding a 7-day low flow once every ten years, the ${}_7Q_{10}$ (or else the biologically based design flow of ${}_4Q_3$) usually serves as the appropriate stream flow because it is generally conservative and commonly available. Thus, 1/4 ${}_7Q_{10}$ or 1/4 ${}_4Q_3$ is the default stream flow considered in the rule. However, alternative site-specific stream flows may be applied.

However, it is recognized there can be scenarios when mixing and dissipation of thermal discharges is not rapid. For this reason, the rule requires mixing zone analyses to be completed as a part of the permitting process. Alternatively, diffusers and other similar mechanical devices can be installed to increase mixing and dissipation of thermal discharges.

DEFAULT WATER QUALITY-BASED EFFLUENT LIMITATION CALCULATIONS

General

A WQBEL for temperature shall be calculated and included in a WPDES permit for each month that a heated effluent is discharged from a facility or operation. An acute WQBEL is to be calculated using the appropriate acute water quality criteria from NR 102 for each month. A sub-lethal WQBEL is to be calculated using the appropriate sub-lethal water quality criteria from NR 102 for each month.

Default WQBELs are calculated using two basic equations - one specific for unidirectional flowing water bodies, and one specific for inland lake, impoundment, or Great Lake water bodies. The purpose of each equation is to determine of the amount of heat (in terms of discharge temperature) a receiving water can assimilate without adversely affecting fish and other aquatic life. Specifically, the default WQBEL equation theoretically calculates the maximum allowable effluent temperature that can be discharged to assure the water quality criterion (acute or sub-lethal) will not be exceeded at the edge of the allowed mixing zone at the site.

WPDES permittees have the option of using an alternative site-specific WQBEL calculation approach, rather than the default WQBEL calculations. Limits based on an alternative site-specific WQBEL calculation approach cannot be included in a WPDES permit unless the approach is approved by the Department.

Unidirectional Flowing Water Bodies

The following equation is used to calculate WQBELs for discharges to undirectional flow water bodies not classified as limited aquatic life or wastewater effluent channels:

$$WQBEL = [((WQC - T_a)(Q_s + (1 - f)Q_e)) / Q_e] + T_a$$

Where:

WQBEL = Water quality-based effluent limitation (in degrees Fahrenheit),
WQC = Water quality criteria (in degrees Fahrenheit),
T_a = Ambient temperature, expressed in degrees Fahrenheit,

Q_s	=	1/4 7Q10 (or other) receiving stream flow in mgd,
f	=	Fraction of the effluent flow that is withdrawn from the receiving water, where f ranges from 0 to 1 and is unitless, and
Q_e	=	Highest daily maximum (or other) effluent flow rate in mgd.

The T_a and WQC variables come from Tables 2-5 in NR 102 or Table 7 of this document (Table 7 contains the same information in Tables 2-5 of NR 102). The Q_s variable is for the receiving water and should be as representative of the conditions immediately near the discharge as possible. Stream flow and the calculated 1/4 7Q10 stream flow can be obtained from USGS, or through other means. The Q_e variable shall be the highest daily maximum effluent flow rate, expressed as mgd, which has occurred for each month of the year and represents normal operating conditions. However, for dischargers that have seasonal discharges, discharges proportional to stream flow, or other unusual discharge situations Q_e shall be determined on a case-by-case basis.

This WQBEL equation represents a heat balance mixing-type analysis, in which evaporative heat loss is not considered because mixing is assumed to be rapid and complete. This heat balance analysis is equivalent to a mass balance approach, making it equivalent to other codified limit calculation procedures.

This same equation is used for determining both acute and sub-lethal WQBELs, the only difference is that the WQC variable is changed from the acute water quality criterion for the given month to the sub-lethal water quality criterion.

Inland Lakes or Impoundments or Great Lakes

The following equation is used to calculate WQBELs for discharges to inland lake, impoundment, or Great Lakes water bodies not classified as limited aquatic life:

$$\text{WQBEL} = [(\text{WQC} - T_a)/(e^{-a})] + T_a$$

Where:

WQBEL	=	Water quality-based effluent limitation (in degrees Fahrenheit),
WQC	=	Water quality criteria (in degrees Fahrenheit),
T_a	=	Ambient temperature, expressed in degrees Fahrenheit, and
e^{-a}	=	An empirical factor; the exponent "a" is calculated as follows: $a = [(A)(54.7 + B(150))] / [(8{,}345{,}000)(Q_e)]$

Where:

A = Area of mixing zone in square feet, as follows:

Maximum Area Allowed (square feet)		Water Body
31,416	=	inland lake or impoundment off-shore discharge
15,708	=	inland lake or impoundment shore discharge
15,708	=	Great Lakes harbor discharge
3,141,593	=	Great Lakes off-shore discharge
3,125,000	=	Great Lakes shore discharge

Additionally, a department approved site-specific mixing zone based on a mixing zone study may be substituted for the default mixing zone provisions of this subsection (specified above).

The maximum area of the mixing zone is subject to all applicable portions of s. NR 102.05(3).

B = A coefficient which is a function of T_a, as follows:

T_a	B
≤ 59.9	0.405
60-69.9	0.555
70-79.9	0.667
≥ 80	0.990

Q_e = Highest daily maximum (or other) effluent flow rate in mgd.

This equation is a derivation of one presented in the "Industrial Waste Guide on Thermal Pollution" (Federal Water Pollution Control Administration [FWPCA] September 1968, pg. 102 - which is referenced as Edinger and Geyer 1965, pg. 113). The T_a and WQC variables come from Tables 2-5 in NR 102 or Table 7 of this document (Table 7 contains the same information in Tables 2-5 of NR 102). The area of the mixing zone (A) is from U.S. Fish and Wildlife models. The coefficient "B" is presented on page 93 of the FWPCA document, in which it is referenced as Edinger and Geyer (1965, pg. 50). The exponent "a" is derived from a $= (K)(A) \div [(P)(C_p)(Q)]$ - see Appendix 13 for the complete derivation of this equation into the one used in the current thermal rule to determine the exponent "a". The Q_e variable shall be the highest daily maximum effluent flow rate, expressed as mgd, which has occurred for each month of the year and represents normal operating conditions. However, for dischargers that have seasonal discharges, discharges proportional to stream flow, or other unusual discharge situations Q_e shall be determined on a case-by-case basis.

This WQBEL equation represents a conservative heat loss analysis. It is "conservative" in terms of not considering mixing, but rather only loss to the atmosphere, which makes this analysis different than that for other codified limit calculation procedures because toxic substances and other pollutants are not assumed to be lost to the atmosphere. Primary assumptions in this analysis include uniform outward effluent dispersal from a discharge point and that the mixing zone acts as a cooling pond.

This same equation is used for determining both acute and sub-lethal WQBELs, the only difference is that the WQC variable is changed from the acute water quality criterion for the given month to the sub-lethal water quality criterion.

AN EFFLUENT LIMITATION TO PROTECT PUBLIC HEALTH AND WELFARE

Throughout NR 106 subchapter V an effluent temperature limit of 120°F is applied to various situations and discharges. The 120°F effluent limit is based on the Public Health and Welfare temperature criterion discussed above and is designed to protect humans from scalding. Please refer to the "Temperature Criteria for Public Health and Welfare" section in this TSD for more detailed information on the basis for the criterion.

QS:QE RATIO APPROACH

The limitations determined by any of the methods mentioned above are to be applied via a grid based on Qs:Qe ratio, as follows:

	Warm & LFF Cut-Offs	Cold Cut-Offs	End-of Pipe Permit Limit
A	Qs:Qe ≥ 20:1	Qs:Qe ≥ 30:1	120 F
B	20:1 > Qs:Qe > 2:1	30:1 > Qs:Qe > 2.5:1	Lower of 1) 120 F or 2) sub-lethal limit (no exceedance of 120 F)
C	Qs:Qe ≤ 2:1	Qs:Qe ≤ 2.5:1	Sub-lethal and Acute limits as per the proposed rule (no exceedance of 120 F)

A = When both sub-lethal and acute WQBELs are always > 120 F, < 20% of ¼ 7Q10 used.
B = When acute WQBELs are always > 120 F (except summer months in cold water at the lower Qs:Qe ratios in this range) and the sub-lethal WQBELs will drive when the mixing zone will be > 40-60% of ¼ 7Q10 for 120 F.
C = When acute WQBELs are always < 120 F.

The Qs:Qe ratio cut-offs are used to determine basic permit conditions. The cut-offs are based on the integration of several analyses that determine the percentage of ¼ 7Q10 used by a discharge of 120 F at various Qs:Qe ratios and water types <u>and</u> default sub-lethal and acute limits at various Qs:Qe ratios and water types. This approach considers all unidirectional flowing water bodies into two groupings – cold waters and all others (except those designated as limited aquatic life). It is believed this approach will streamline the thermal permitting process in the majority of cases.

EFFLUENT LIMITATIONS FOR LIMITED AQUATIC LIFE WATERS

The instantaneous maximum effluent temperature limit of 95°F is applied to Limited Aquatic Life (LAL) waters that are not wastewater effluent channels, as supported by the information in the "Temperature Criteria for Limited Aquatic Life Waters" section above and summarized in Table 8. In all cases fish and aquatic life uses downstream of LAL waters, must be considered and protected. Additionally, wetland protections under ch. NR 103 must be met.

The instantaneous maximum effluent temperature limit of 120°F is applied to heated discharges to LAL waters that are wastewater effluent channels because these channels are designed and/or used to transport effluent, and are as such, essentially conduits carrying effluent. In all cases fish and other aquatic life uses and communities downstream of LAL waters must be considered and protected.

ALTERNATIVE SITE-SPECIFIC WATER QUALITY-BASED EFFLUENT LIMITATION CALCULATIONS

Alternative methods for calculating or generating water quality-based effluent limitations may be used. These alternative methods may incorporate site-specific characteristics and data. However, any alternative method must be approved by the Department prior to being used in a WPDES permit.

LIMITATIONS FOR VARIABLE EFFLUENT FLOWS

Effluent flow-related WQBELs may be calculated for those discharges with regularly fluctuating effluent flow. This provision is provided to allow permittees of these types of discharges a range of effluent temperature limitations to operate within, rather than a single limitation.

COLD SHOCK & RATE OF TEMPERATURE CHANGE

The purpose of the cold shock and rate of temperature change provisions in NR 106 is to provide flexibility in the rule to protectively handle two potential scenarios resulting from certain site-specific discharges. Both are to be handled on a case-by-case basis to meet the cold shock and rate of temperature change standards for NR 102.

APPENDICES

Appendix 1

Glossary of Terms and Acronyms

Acclimation Temperature

A relatively stable laboratory or field temperature, which fish and/or other organisms have physiologically adjusted to. This is a temperature in the tolerance zone that test fish are experimentally exposed to for several days prior to a tolerance test (such as a UILT test).

Acute

Refers to having a sudden onset, lasting a short time or a stimulus severe enough to induce a response rapidly. Can be used to define either the exposure or the response to an exposure (effect). Acute effects are any effects resulting in death or immobilization. In reference to this rule, acute criteria represent the maximum water temperatures that aquatic organisms can exist in without incurring an acute effect.

Ambient Temperature

The typical existing temperature of a surface water outside the direct influence of any point source discharge, which may include daily and seasonal changes.

cfs

Cubic feet per second, usually pertaining to stream or effluent flow. 1 cfs = 0.64584 mgd.

Cold Shock

The exposure of aquatic organisms to a rapid decrease in temperature and a sustained exposure to low temperature that induces abnormal behavioral or physiological performance and often leads to death.

Daily Maximum Effluent Temperature

The highest temperature measured in a calendar day.

Daily Maximum Effluent Temperature Limitation

The maximum allowable daily effluent temperature.

Great Lakes

In terms of this rule, refers to the open Wisconsin waters of Lake Superior, Lake Michigan, Green Bay, and Chequamegon Bay, as well as adjoining open waters that exhibit characteristics of Lake Superior, Lake Michigan, Green Bay, or Chequamegon Bay, or in other ways are determined by the Department of Natural Resources to be equivalent to these waters for purposes of regulating discharges of heat to them.

Growth Optimum

Temperature under experimental conditions at which growth rates, expressed as weight gain/unit time, are maximal for the life stage being tested.

Instantaneous Maximum Effluent Temperature Limitation

The maximum allowable effluent temperature determined from any temperature measurement such as the value of a grab sample or at any time during continuous monitoring over a given period of regulation (e.g. a month).

mgd

Million gallons per day, usually pertaining to stream or effluent flow. 1 mgd = 1.54837 cfs.

New Facility

Any new point source facility or new point source discharge that commences operation after the effective date of this subchapter.

Physiological Optimum

Temperature under experimental conditions approximating that for optimum growth, stamina, heart performance, and other functions. When physiological optimum is considered, stipulation must be made whether it is for general conditions, a specific function (e.g. spawning), or an age (e.g. juvenile).

Sub-Lethal

Below the threshold that directly causes death. For purposes of this rule, sub-lethal effects are those that result in inadequate gonad development, gamete production and viability, spawning, or growth. In reference to this rule, sub-lethal criteria represent the maximum water temperatures that aquatic organisms can exist in without incurring a sub-lethal effect.

Temperature Conversion Factor

Degree Fahrenheit = (9/5 x degree Celsius) + 32

Tolerance

The ability of an organism to function indefinitely under temperature conditions which are outside of the physiological optimum.

UILT (Upper Incipient Lethal Temperature)

The upper temperature where 50% mortality of a given population is observed for a given acclimation temperature. The UILT increases as acclimation temperature increases to a point where higher acclimation temperatures have no effect.

UUILT (Ultimate Upper Incipient Lethal Temperature)

The highest temperature at which tolerance does not increase with increasing acclimation temperature.

Water Quality Standards

Applicable water quality standards set forth in chs. NR 102–104, or any federally promulgated water quality standards applicable to surface waters of the state.

Weekly Average Effluent Temperature

The arithmetic mean of all daily maximum effluent temperature values recorded in a calendar week (Sunday – Saturday).

Weekly Average Effluent Temperature Limitation

The maximum allowable weekly average temperature determined as the arithmetic mean of all daily maximum effluent temperature values recorded in a calendar week (Sunday – Saturday).

WPDES

Wisconsin pollutant discharge elimination system – in regards to a permit under ch. 283, Stats.

WQBEL

Water quality-based effluent limitation, as pertains to regulation of discharges to waters of the State of Wisconsin.

Zero Net Growth

Temperatures under experimental conditions at which instantaneous growth and mortality rates for populations are equal. Growth rates are considered to be an overall indicator of environmental quality and seemingly are the most sensitive of various performance functions, particularly if expressed as zero net growth when food is not limiting.

Appendix 2

Species Considered in the Development of Thermal Water Quality Criteria

A. Species Used for All Waters Except Inland Lakes

Common Name	Classification	Used for Acute ?	Used for Spawning ?	Used for Growth ?
alewife	great lakes	yes	yes	yes
american brook lamprey	cool	no	yes	no
banded darter	warm	no	no	no
banded killifish	warm	no	yes	no
bigmouth buffalo	warm	no	yes	no
bigmouth shiner	warm	no	no	no
black buffalo	warm	no	no	no
black bullhead	LFF	no	no	no
black crappie	warm	no	yes	yes
black redhorse	warm	no	yes	no
blackchin shiner	warm	no	no	no
blackfin cisco	extirpated/extinct	no	no	no
blacknose dace	warm_LFF	yes	yes	no
blacknose shiner	warm	no	no	no
blackside darter	warm	no	yes	no
blackstripe topminnow	warm	no	no	no
bloater	great lakes	yes	no	yes
blue sucker	warm	no	yes	no
bluegill	warm	yes	yes	yes
bluntnose darter	warm MS R only	no	no	no
bluntnose minnow	warm/great lakes_LFF	yes	yes	no
bowfin	warm/great lakes	no	yes	no
brassy minnow	warm	no	yes	no
brook silverside	warm	no	yes	no
brook stickleback	LFF	no	yes	no
brook trout	cold/great lakes	yes	yes	yes
brown bullhead	warm	yes	yes	no
brown trout	cold/great lakes	yes	yes	yes
bullhead minnow	warm	no	yes	no
burbot	cool/great lakes	no	yes	no
central mudminnow	LFF	no	yes	no
central stoneroller	warm	no	yes	no
channel catfish	warm	yes	yes	yes
chestnut lamprey	warm	no	yes	no
chinook salmon	cold/great lakes	yes	yes	yes
cisco/lake herring	cold/great lakes	yes	yes	no
coho salmon	cold/great lakes	yes	yes	yes
common carp	undesired exotic_LFF/great lakes	no	no	no
common shiner	warm/great lakes	yes	yes	no
creek chub	warm_LFF	yes	yes	no
creek chubsucker	extirpated/extinct	no	no	no
crystal darter	warm	no	no	no

Common Name	Classification	Used for Acute ?	Used for Spawning ?	Used for Growth ?
deepwater cisco	extirpated/extinct	no	no	no
deepwater sculpin	great lakes	no	yes	no
emerald shiner	warm/great lakes	yes	yes	yes
fantail darter	warm	no	yes	no
fathead minnow	LFF/great lakes	yes	yes	yes
finescale dace	warm	yes	yes	yes
flathead catfish	warm	no	yes	no
freshwater drum	warm/great lakes	no	yes	no
ghost shiner	extirpated/extinct	no	no	no
gilt darter	warm	no	yes	no
gizzard shad	warm/great lakes	yes	yes	no
golden redhorse	warm	no	yes	no
golden shiner	LFF	yes	yes	no
goldeye	warm	no	yes	no
goldfish	undesired exotic_LFF/great lakes	no	no	no
grass pickerel	warm	no	yes	no
gravel chub	warm	no	yes	no
greater redhorse	warm	no	yes	no
green sunfish	LFF	yes	yes	yes
highfin carpsucker	warm	no	yes	no
hornyhead chub	warm	no	yes	no
iowa darter	warm	no	yes	no
ironcolor shiner	extirpated/extinct	no	no	no
johnny darter	warm	no	yes	no
kiyi	great lakes	no	yes	no
kokanee salmon	cold	yes	no	no
lake chub	great lakes	no	yes	no
lake chubsucker	warm	no	yes	no
lake sturgeon	warm/great lakes	no	yes	no
lake trout	great lakes	no	yes	no
lake whitefish	great lakes	yes	yes	no
largemouth bass	warm	yes	yes	yes
largescale stoneroller	warm	no	yes	no
least darter	warm	no	yes	no
logperch	warm	no	yes	no
longear sunfish	warm	yes	yes	no
longnose dace	warm/great lakes	no	yes	no
longnose gar	warm	no	yes	no
longnose sucker	cold/great lakes	no	yes	no
mimic shiner	warm/great lakes	no	no	no
mississippi silvery minnow	warm	no	yes	no
mooneye	warm	no	yes	no
mottled sculpin	cool	no	yes	no
mud darter	warm	no	no	no
muskellunge	warm/great lakes	yes	yes	yes
ninespine stickleback	great lakes	no	yes	no
northern brook lamprey	warm	no	yes	no
northern hog sucker	warm	yes	yes	no
northern pike	warm/great lakes	yes	yes	yes
northern redbelly dace	warm	yes	yes	yes

Common Name	Classification	Used for Acute ?	Used for Spawning ?	Used for Growth ?
orangespotted sunfish	warm	no	yes	no
ozark minnow	warm	no	no	no
paddlefish	warm	no	yes	no
pallid shiner	warm MS R only	no	no	no
pearl dace	warm	no	yes	no
pink salmon	great lakes stray	yes	yes	no
pirate perch	warm	no	no	no
pugnose minnow	warm	no	no	no
pugnose shiner	warm	no	yes	no
pumpkinseed	warm	yes	yes	no
pygmy whitefish	great lakes	no	no	no
quillback	warm	no	yes	no
rainbow darter	warm	no	no	no
rainbow smelt	great lakes	no	yes	yes
rainbow trout	cold/great lakes	yes	yes	yes
red shiner	warm stray	no	yes	no
redfin shiner	warm	no	no	no
redside dace	cool	no	no	no
river carpsucker	warm	no	yes	no
river darter	warm	no	yes	no
river redhorse	warm	no	yes	no
rock bass	warm	no	yes	no
rosyface shiner	warm	no	yes	no
round whitefish	great lakes	no	yes	no
sand shiner	warm	no	yes	no
sauger	warm/great lakes	yes	yes	yes
shorthead redhorse	warm	no	yes	no
shortjaw cisco	great lakes	no	no	no
shortnose cisco	extirpated/extinct	no	no	no
shortnose gar	warm	no	yes	no
shovelnose sturgeon	warm	no	yes	no
silver chub	warm	no	no	no
silver lamprey	warm	no	yes	no
silver redhorse	warm	no	yes	no
skipjack herring	warm stray	no	no	no
slender madtom	warm	no	no	no
slenderhead darter	warm	no	yes	no
slimy sculpin	cold/great lakes	yes	yes	no
smallmouth bass	warm/great lakes	no	yes	yes
smallmouth buffalo	warm	no	yes	no
southern redbelly dace	warm	no	yes	no
speckled chub	warm	no	no	no
spoonhead sculpin	great lakes	no	yes	no
spotfin shiner	warm	no	yes	no
spottail shiner	warm/great lakes	yes	yes	yes
spotted sucker	warm	no	yes	no
starhead topminnow	warm	no	no	no
stonecat	warm	no	no	no
striped shiner	warm	no	no	no
suckermouth minnow	warm	no	yes	no

Common Name	Classification	Used for Acute ?	Used for Spawning ?	Used for Growth ?
tadpole madtom	warm	no	no	no
trout-perch	warm/great lakes	no	yes	no
walleye	warm/great lakes	yes	yes	yes
warmouth	warm	no	yes	no
weed shiner	warm	no	no	no
western sand darter	warm	no	no	no
white bass	warm/great lakes	yes	yes	yes
white crappie	warm	no	yes	yes
white perch	undesired exotic_great lakes	no	no	no
white sucker	cool/great lakes_LFF	yes	yes	yes
yellow bass	warm	no	yes	no
yellow bullhead	LFF	no	no	no
yellow perch	warm/great lakes	yes	yes	yes

SUMMARY

Total # of Species:	# of Species Used for each Criteria Type:		
155	38	113	27
	Acute	Spawning	Growth

Explanations:

Classification = Type of water(s) the species is known to exist in (in Wisconsin)

Used for Acute ? = Data from the species labeled "yes" were used to develop water use Classification-specific Acute Water Quality-based Thermal Criteria

Used for Spawning ? = Data from the species labeled "yes" were used to develop water use Classification-specific Maximum Spawning Temperature Water Quality-based Thermal Criteria

Used for Growth ? = Data from the species labeled "yes" were used to develop water use Classification-specific Maximum No Growth Temperature Water Quality-based Thermal Criteria

B. Species Used for Inland Lake Waters

		Northern Inland Lakes			Southern Inland Lakes		
			Used for:			Used for:	
Common Name	Classification	Acute?	Spawning?	Growth?	Acute?	Spawning?	Growth?
banded killifish	warm	no	yes	no	no	yes	no
bigmouth buffalo	warm	no	no	no	no	yes	no
black bullhead	LFF	no	no	no	no	no	no
black crappie	warm	no	yes	yes	no	yes	yes
blackchin shiner	warm	no	no	no	no	no	no
blacknose shiner	warm	no	no	no	no	no	no
bluegill	warm	yes	yes	yes	yes	yes	yes
bluntnose minnow	warm/great lakes_LFF	yes	yes	no	yes	yes	no
bowfin	warm/great lakes	no	yes	no	no	yes	no
brassy minnow	warm	no	yes	no	no	no	no
brook silverside	warm	no	yes	no	no	yes	no
brook stickleback	LFF	no	yes	no	no	yes	no
brown bullhead	warm	yes	yes	no	yes	yes	no
burbot	cool/great lakes	no	yes	no	no	no	no
central mudminnow	LFF	no	yes	no	no	yes	no
channel catfish	warm	yes	yes	yes	yes	yes	yes
common shiner	warm/great lakes	yes	yes	no	yes	yes	no
emerald shiner	warm/great lakes	yes	yes	yes	yes	yes	yes
fantail darter	warm	no	yes	no	no	yes	no
fathead minnow	LFF/great lakes	yes	yes	yes	yes	yes	yes
finescale dace	warm	yes	yes	yes	no	no	no
freshwater drum	warm/great lakes	no	no	no	no	yes	no
gizzard shad	warm/great lakes	no	no	no	yes	yes	no
golden shiner	LFF	yes	yes	no	yes	yes	no
grass pickerel	warm	no	no	no	no	yes	no
greater redhorse	warm	no	yes	no	no	yes	no
green sunfish	LFF	yes	yes	yes	yes	yes	yes
iowa darter	warm	no	yes	no	no	yes	no
johnny darter	warm	no	yes	no	no	yes	no
lake chubsucker	warm	no	no	no	no	yes	no
lake sturgeon	warm/great lakes	no	yes	no	no	yes	no
largemouth bass	warm	yes	yes	yes	yes	yes	yes
least darter	warm	no	yes	no	no	yes	no
logperch	warm	no	yes	no	no	yes	no
longear sunfish	warm	yes	yes	no	yes	yes	no
longnose gar	warm	no	no	no	no	yes	no
mimic shiner	warm/great lakes	no	no	no	no	no	no
mottled sculpin	cool	no	yes	no	no	yes	no
muskellunge	warm/great lakes	yes	yes	yes	yes	yes	yes
northern pike	warm/great lakes	yes	yes	yes	yes	yes	yes
northern redbelly dace	warm	yes	yes	yes	no	no	no
pearl dace	warm	no	yes	no	no	no	no
pugnose shiner	warm	no	yes	no	no	yes	no
pumpkinseed	warm	yes	yes	no	yes	yes	no
rock bass	warm	no	yes	no	no	yes	no
sauger	warm/great lakes	yes	yes	yes	yes	yes	yes

		Northern Inland Lakes			Southern Inland Lakes		
			Used for:			Used for:	
Common Name	Classification	Acute?	Spawning?	Growth?	Acute?	Spawning?	Growth?
shorthead redhorse	warm	no	yes	no	no	yes	no
smallmouth bass	warm/great lakes	no	yes	yes	no	yes	yes
spotfin shiner	warm	no	no	no	no	yes	no
spottail shiner	warm/great lakes	yes	yes	yes	yes	yes	yes
tadpole madtom	warm	no	no	no	no	no	no
trout-perch	warm/great lakes	no	yes	no	no	yes	no
walleye	warm/great lakes	yes	yes	yes	yes	yes	yes
warmouth	warm	no	yes	no	no	yes	no
white bass	warm/great lakes	no	no	no	yes	yes	yes
white crappie	warm	no	yes	yes	no	yes	yes
white sucker	cool/great lakes_LFF	yes	yes	yes	yes	yes	yes
yellow bass	warm	no	no	no	no	yes	no
yellow bullhead	LFF	no	no	no	no	no	no
yellow perch	warm/great lakes	yes	yes	yes	yes	yes	yes

Total # of Species:		# of Species Used for each Criteria Type:					
60		**21**	**45**	**18**	**21**	**49**	**17**

Explanations:

Classification = Type of water(s) the species is known to exist in (in Wisconsin)

Northern Inland Lakes = Lakes north of State Highway 10

Southern Inland Lakes = Lakes south of State Highway 10

Used for Acute ? = Data from the species labeled "yes" were used to develop water use Classification-specific Acute Water Quality-based Thermal Criteria

Used for Spawning ? = Data from the species labeled "yes" were used to develop water use Classification-specific Maximum Spawning Temperature Water Quality-based Thermal Criteria

Used for Growth ? = Data from the species labeled "yes" were used to develop water use Classification-specific Maximum No Growth Temperature Water Quality-based Thermal Criteria

Appendix 3

Species Existence in Great Lakes Waters

Y = species exists in the waterbody N = species does not exist in the waterbody

Species	Southern Green Bay*1	Northern Green Bay*2	Northern Lake Michigan*3	Southern Lake Michigan*4	Lake Superior	Chequamegon Bay
alewife	Y	Y	Y	Y	Y, rare	Y, rare
bloater	N	Y	Y	Y	Y	N
bluntnose minnow	Y	Y, rare	Y, harbors	Y	Y	Y
bowfin	Y	Y	Y	Y	N	N
brook trout	N	Y	Y	Y	Y	Y
brown trout	N	Y	Y	Y	Y	Y
burbot	Y	Y	Y	Y	Y	Y
chinook salmon	N	Y	Y	Y	Y	Y
cisco/lake herring	N	Y, rare	Y, rare	Y, very rare	Y	Y
coho salmon	N	Y	Y	Y	Y	Y
common shiner	Y	Y	Y	Y	Y	Y
deepwater sculpin	N	Y	Y	Y	Y	Y, rare
emerald shiner	Y	Y	Y	Y	Y	Y
fathead minnow	Y	Y, rare	Y, harbors	Y	Y, harbors	Y
freshwater drum	Y	Y	Y, rare	Y, rare	N	N
gizzard shad	Y	Y	Y	Y	N	N
kiyi	N, extirpated	N, extirpated	N, extirpated	N, extirpated	Y	N
lake chub	N	Y, rare	Y, rare	Y, rare	Y	Y, rare
lake sturgeon	Y	Y	Y	Y	Y	Y
lake trout	Y, rare	Y	Y	Y	Y	Y
lake whitefish	N	Y	Y	Y	Y	Y
longnose dace	Y	Y	Y	Y	N	N
longnose sucker	Y	Y	Y	Y	Y	Y
muskellunge	Y	Y	Y, rare	Y, very rare	Y, rare	N
ninespine stickleback	Y	Y	Y	Y	Y	Y
northern pike	Y	Y	Y, harbors	Y	Y, harbors	Y
pink salmon	Y, very rare	Y, very rare	Y, rare	Y, rare	Y, rare	Y, rare
rainbow smelt	Y	Y	Y	Y	Y	Y
rainbow trout	Y	Y	Y	Y	Y	Y
round whitefish	Y	Y	Y	Y	Y	Y
sauger	Y	Y, rare	N	N	N	N
shortjaw cisco	N, extirpated	N, extirpated	N, extirpated	N, extirpated	Y	N
slimy sculpin	N	Y	Y	Y	Y	Y
smallmouth bass	Y	Y	Y	Y	Y	Y
spoonhead sculpin	N, extirpated	Y, very rare	Y, rare	Y, rare	Y	Y
spottail shiner	Y	Y	Y	Y	Y	Y
trout-perch	Y	Y	Y	Y	Y	Y
walleye	Y	Y	Y, harbors	Y	Y	Y
white bass	Y	Y	Y, rare	Y, rare	Y	Y
white sucker	Y	Y	Y	Y	Y	Y
yellow perch	Y	Y	Y	Y	Y	Y

***1** = South of the Brown County Line (essentially south of Long Tail - Little Tail Points), ***2** = North of the Brown County Line (essentially north of Long Tail - Little Tail Points), ***3** = North of the Milwaukee/Ozaukee County line, ***4** = South of the Milwaukee/Ozaukee County line

Information in this table was provided by Regional DNR Staff in the Fisheries Management & Habitat Protection Bureau and a fisheries research scientist in the Integrated Science Services Bureau (March - April, 2003).

Appendix 4

Summary of Species Data Used for Acute Temperature Criteria Development

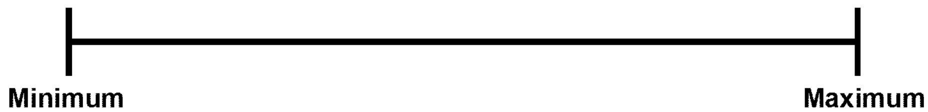
	Common Name	Classification	n	Acclimation Temp Range (F)	UILT Range (F)
1	alewife	great lakes	15	41 - 83	59 - 92
2	blacknose dace	warm_LFF	9	41 - 77	80 - 86
3	bloater	great lakes	5	41 - 77	72 - 80
4	bluegill	warm	18	34 - 91	74 - 101
5	bluntnose minnow	warm/great lakes_LFF	8	41 - 77	79 - 92
6	brook trout	cold/great lakes	12	37 - 77	72 - 79
7	brown bullhead	warm	25	41 - 104	82 - 106
8	brown trout	cold/great lakes	9	41 - 73	72 - 78
9	channel catfish	warm	9	59 - 95	87 - 100
10	chinook salmon	cold/great lakes	8	41 - 77	71 - 77
11	cisco/lake herring	cold/great lakes	5	36 - 77	68 - 80
12	coho salmon	cold/great lakes	6	41 - 73	73 - 77
13	common shiner	warm/great lakes	13	41 - 86	80 - 92
14	creek chub	warm_LFF	12	41 - 86	76 - 90
15	emerald shiner	warm/great lakes	10	41 - 77	73 - 87
16	fathead minnow	LFF/great lakes	4	50 - 86	82 - 93
17	finescale dace	warm	7	48 - 77	81 - 90
18	gizzard shad	warm/great lakes	6	77 - 95	93 - 98
19	golden shiner	LFF	13	32 - 86	80 - 94
20	green sunfish	LFF	3	68 - 86	95 - 104
21	kokanee salmon	cold	5	41 - 73	72 - 77
22	lake whitefish	great lakes	5	41 - 72.5	69 - 80
23	largemouth bass	warm	18	59 - 95	89 - 104
24	longear sunfish	warm	4	60 - 95	88 - 99.5
25	muskellunge	warm/great lakes	4	77 - 86	90.5 - 92
26	northern hog sucker	warm	6	64 - 91	81 - 93
27	northern pike	warm/great lakes	7	43 - 86	69 - 92
28	northern redbelly dace	warm	10	43 - 77	80 - 90.5
29	pink salmon	great lakes stray	5	41 - 75	71 - 75
30	pumpkinseed	warm	12	46 - 93	76 - 99
31	rainbow trout	cold/great lakes	24	41 - 76	73 - 80
32	sauger	warm/great lakes	10	50 - 79	80 - 88
33	slimy sculpin	cold/great lakes	4	41 - 68	65 - 77
34	spottail shiner	warm/great lakes	10	48 - 79	87 - 100
35	walleye	warm/great lakes	11	45 - 79	81 - 93
36	white bass	warm/great lakes	4	57 - 79	87 - 90
37	white sucker	cool/great lakes_LFF	14	41 - 77	80 - 88
38	yellow perch	warm/great lakes	10	41 - 86	70 - 92
		Total # of Data Pairs =	**360**		

Appendix 5

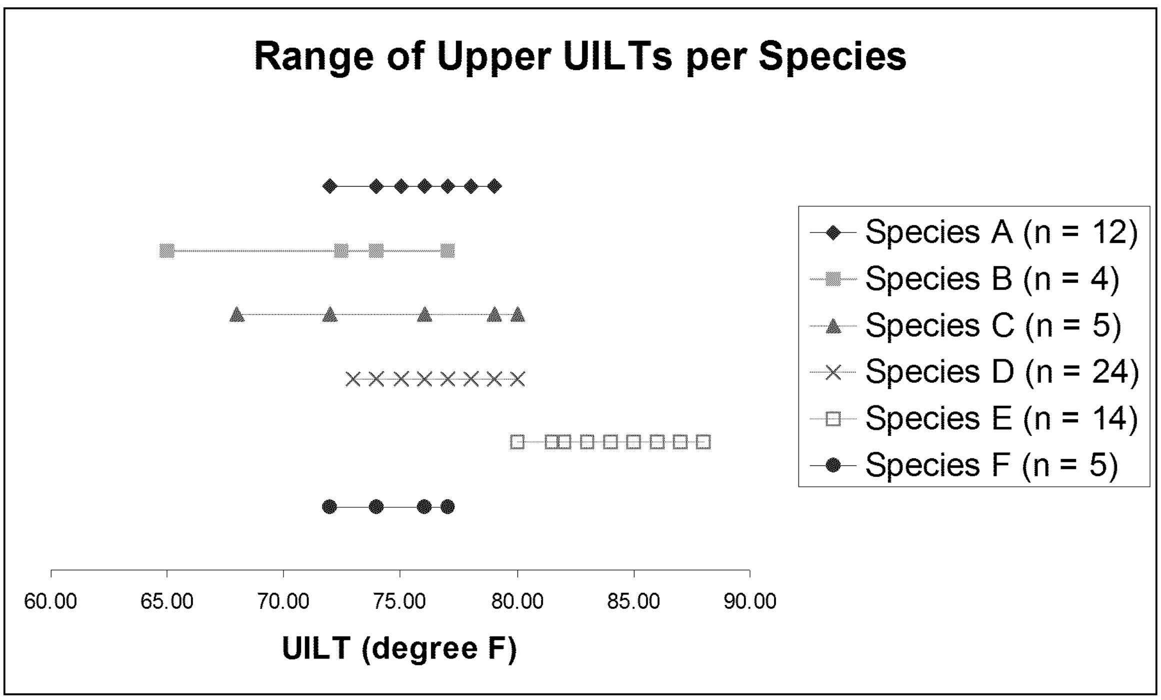
Explanation of How the Water Quality-Based Acute Thermal Criteria are Developed

This appendix is intended to explain in simple terms the general and statistical approaches used in developing the water quality-based acute criteria as part of the thermal rule revisions in Chapter NR 102. The data used in this example are real, but are only a subset of one data set (only a subset was used to keep the figures simple). It is important to note that this example represents the development of acute criteria for one water use or community (such as cold water), and would need to be repeated for each use or community that acute criteria are being developed for.

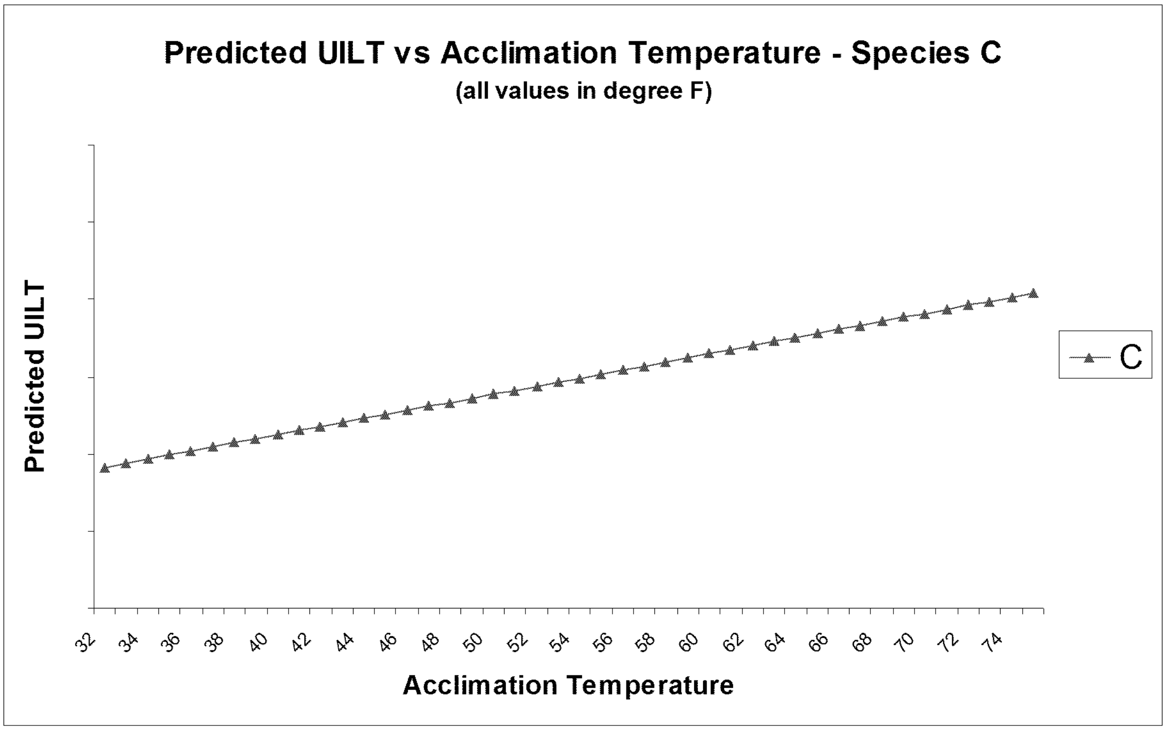
In general, for each species there are maximum and minimum temperature thresholds (a range) that they can live within:

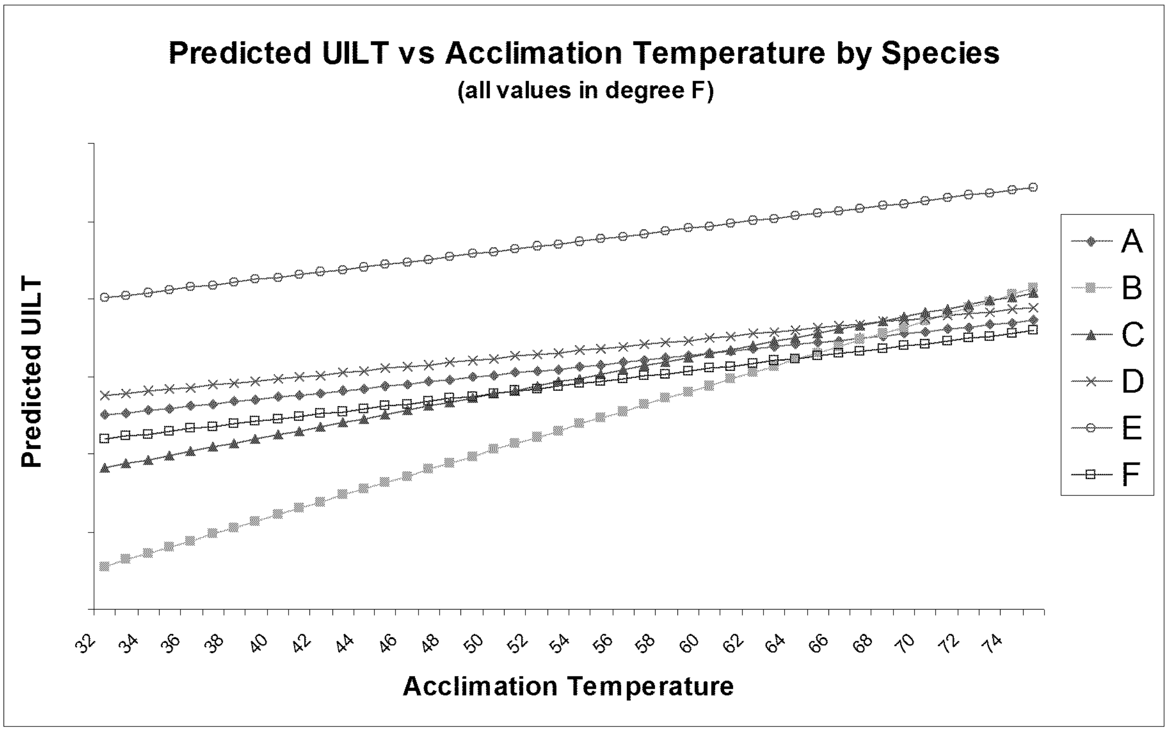


The maximum temperature of this range increases as the water temperature the organism is acclimated to increases, until an absolute maximum threshold temperature is reached that does not increase despite increased acclimation temperature. The Upper Incipient Lethal Temperature (UILT) is the maximum temperature a species can exist in at a given acclimation temperature. The UILT is determined through laboratory investigation/study. The absolute maximum threshold temperature that cannot be exceeded is called the Ultimate Upper Incipient Lethal Temperature (UUILT). Different studies may conclude slightly different UILTs for the same species at the same acclimation temperature, or alternatively may conclude the same UILT for the same species at slightly different acclimation temperatures. UILT - acclimation temperature pairs for species that exist in Wisconsin were organized into appropriate FAL use groups and used to develop the acute water quality-based thermal criteria. The following displays ranges of UILTs for species (A, B, C, D, E, F) in a given FAL use group (e.g. cold water):



Via regression of all UILT - acclimation temperature data pairs for each species, a species-specific predicted UILT can be calculated for any range of temperatures (such as expected ambient temperatures). The following figures display predicted UILT vs temperature plots for different species.

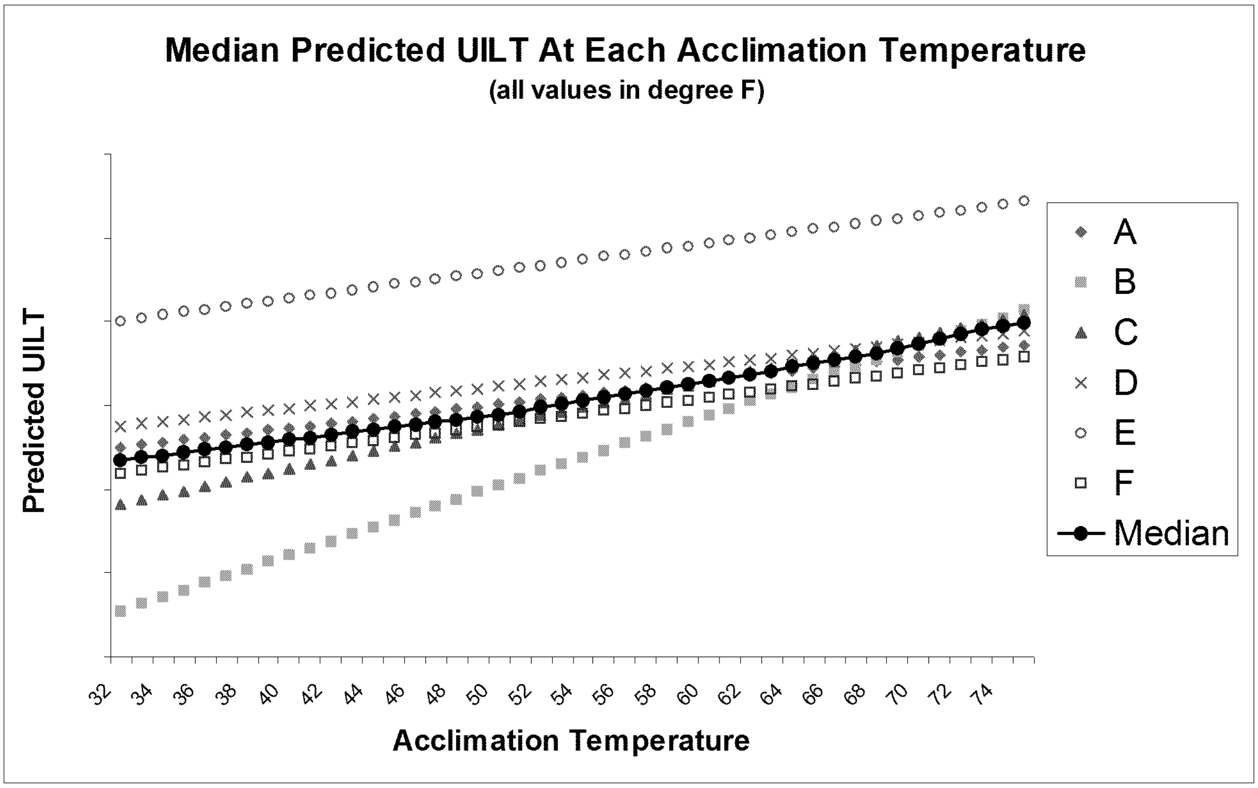




The above data is used to develop either the "Median" approach or the formerly considered "5th" percentile approach, as described below.

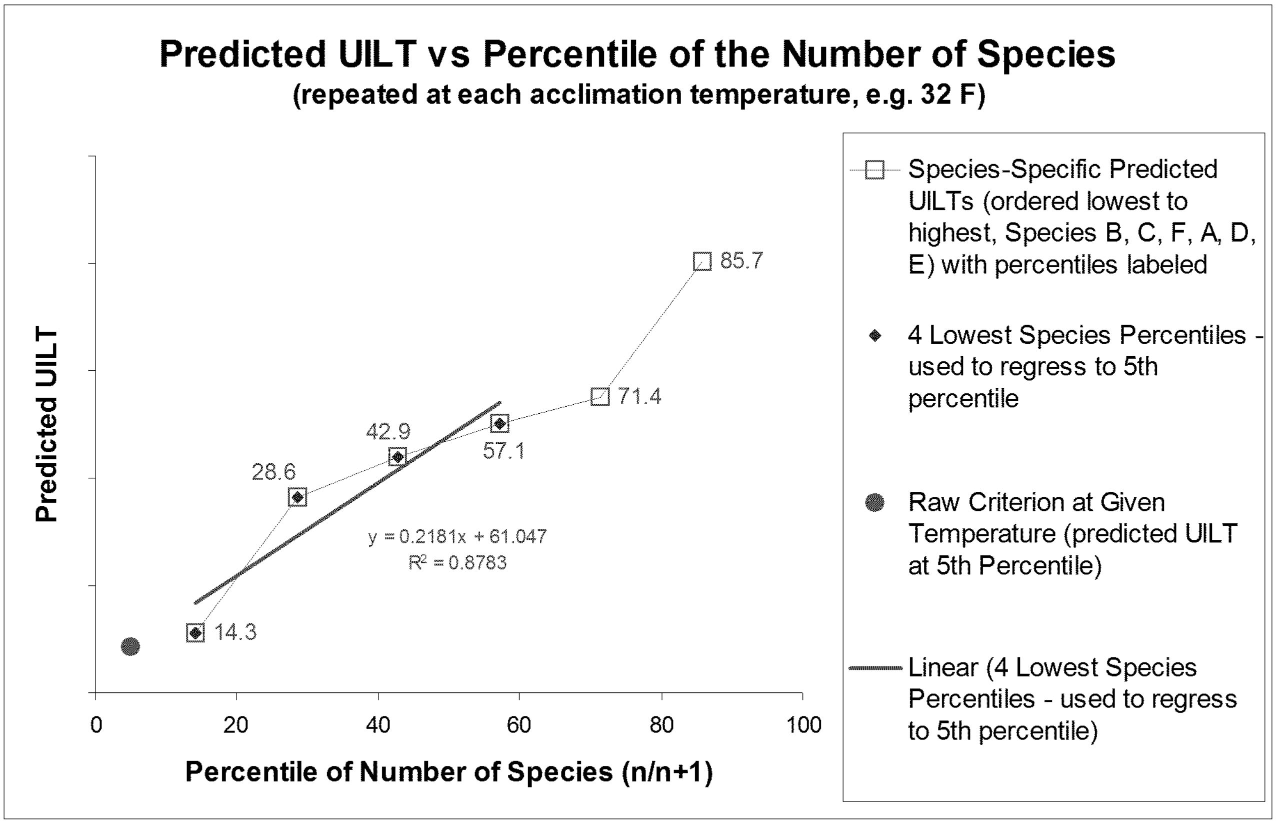
Median Approach

Considering the "Predicted UILT vs Acclimation Temperature by Species" plot in a slightly different way, the species-specific predicted UILTs at each temperature are considered in a ranked order from lowest to highest predicted UILT. The "Median" approach for determining acute criteria (the approach used in this rule revision) is simply the median of each "set" of predicted UILTs at a given temperature. Thus the median is the raw acute criterion at the given temperature (the "raw" criterion is the criterion prior to the application of the 3.6° F safety factor). The following figure displays the development of the raw acute criteria using the median approach:



Formerly Considered Approach

The approach used in the past included one additional step. That step was to use the four lowest species-specific predicted UILTs to regress/extrapolate to the 5th percentile predicted UILT at a given temperature (i.e. repeated for each temperature). The 5th percentile predicted UILT is the raw acute criterion at the given temperature (the "raw" criterion is the criterion prior to the application of the 3.6° F safety factor). This approach is an equivalent modification of one used for developing water quality criteria for conservative toxic pollutants. The following figure displays the development of the raw acute criteria using this formerly considered approach:


Predicted UILT vs Percentile of the Number of Species
(repeated at each acclimation temperature, e.g. 32 F)
Predicted UILT
Percentile of Number of Species (n/n+1)
0
20
40
60
80
100
14.3
28.6
42.9
57.1
71.4
85.7
y = 0.2181x + 61.047
R² = 0.8783
Species-Specific Predicted UILTs (ordered lowest to highest, Species B, C, F, A, D, E) with percentiles labeled
4 Lowest Species Percentiles - used to regress to 5th percentile
Raw Criterion at Given Temperature (predicted UILT at 5th Percentile)
Linear (4 Lowest Species Percentiles - used to regress to 5th percentile)

Appendix 6

SAS Code for Developing Default Acute Water Quality Criteria - Cold Water Example

This appendix displays the SAS code of the statistical analyses used for developing the default acute water quality criteria. Specifically, this appendix displays the SAS code for developing the cold water criteria. The exact same SAS code is used to develop the default acute criteria for other water uses or communities, with the following modifications:

- Replace "cold" <u>anywhere</u> it is found in the code with the appropriate water use or community name (e.g. work.predictcold would be work.predictwarm if developing warm water criteria).
- The data input into the program (under the "DATAFILE …" line near the beginning of the program) must be for the appropriate water use.
- The appropriate species and regression equation data must be used in the "Computing Predicted UILT from Regression Equations" section of the program code.
- Assure the proper range of temperatures are listed in the "Ranking Step" section of the program code (e.g. warm water uses will need a range that includes up to at least "100 - 100.99" °F). Simply add the additional rows of temperatures to expand the code to include the appropriate temperature range.

The SAS Code is:

```
PROC IMPORT OUT= WORK.Thermalacute

DATAFILE= "C:\THERMAL STUFF\NR 102 Stuff\Criteria Development\SASStuff\Acute
Analyses\acutecold_052003.txt"

    DBMS=TAB REPLACE;
    GETNAMES=YES;
    DATAROW=2;

*Regressions for each species;
proc reg data=work.thermalacute;
    by Common_Name;
    model UILT = Acclimation_Temp;

*Analysis of Covariance allowing for different slopes;
proc glm data=work.thermalacute;
    class Common_Name;
    model UILT = Common_Name Acclimation_Temp Common_Name*Acclimation_Temp / solution;
    output out=preds r=resid p=pred;

*Analysis of Covariance for Similar Slopes;
proc glm data=work.thermalacute;
    class Common_Name;
    model UILT = Common_Name Acclimation_Temp / solution;
    output out=preds r=resid p=pred;
```

```
*Computing Predicted UILT from Regression Equations;
data work.predictcold;
    DO Acclimation_Temp = 32 to 90 by 1.0;
    Common_Name = 'brook trout';
    UILT = 67.97774 + 0.14164*Acclimation_Temp;
    output;
    Common_Name = 'brown trout';
    UILT = 66.97151 + 0.13947*Acclimation_Temp;
    output;
    Common_Name = 'chinook salmon';
    UILT = 67.71451 + 0.11480*Acclimation_Temp;
    output;
    Common_Name = 'cisco/lake herring';
    UILT = 60.75154 + 0.26192*Acclimation_Temp;
    output;
    Common_Name = 'coho salmon';
    UILT = 67.29847 + 0.14183*Acclimation_Temp;
    output;
    Common_Name = 'kokanee salmon';
    UILT = 65.78580 + 0.16176*Acclimation_Temp;
    output;
    Common_Name = 'rainbow trout';
    UILT = 69.57290 + 0.13144*Acclimation_Temp;
    output;
    Common_Name = 'slimy sculpin';
    UILT = 49.41667 + 0.41667*Acclimation_Temp;
    output;
    Common_Name = 'white sucker';
    UILT = 74.80352 + 0.16460*Acclimation_Temp;
    output;
    end;

*Ranking Step -compute final acute value following EPA procedure;
proc format;
value Acclfmt    0='32 -32.99'
                 1='33 -33.99'
                 2='34 -34.99'
                 3='35 -35.99'
                 4='36 -36.99'
                 5='37 -37.99'
                 6='38 -38.99'
                 7='39 -39.99'
                 8='40 -40.99'
                 9='41 -41.99'
                 10='42 -42.99'
                 11='43 -43.99'
```

12='44 -44.99'
13='45 -45.99'
14='46 -46.99'
15='47 -47.99'
16='48 -48.99'
17='49 -49.99'
18='50 -50.99'
19='51 -51.99'
20='52 -52.99'
21='53 -53.99'
22='54 -54.99'
23='55 -55.99'
24='56 -56.99'
25='57 -57.99'
26='58 -58.99'
27='59 -59.99'
28='60 -60.99'
29='61 -61.99'
30='62 -62.99'
31='63 -63.99'
32='64 -64.99'
33='65 -65.99'
34='66 -66.99'
35='67 -67.99'
36='68 -68.99'
37='69 -69.99'
38='70 -70.99'
39='71 -71.99'
40='72 -72.99'
41='73 -73.99'
42='74 -74.99'
43='75 -75.99'
44='76 -76.99'
45='77 -77.99'
46='78 -78.99'
47='79 -79.99'
48='80 -80.99'
49='81 -81.99'
50='82 -82.99'
51='83 -83.99'
52='84 -84.99'
53='85 -85.99'
54='86 -86.99'
55='87 -87.99'
56='88 -88.99'
57='89 -89.99'
58='90 -90.99';

```
*Read data for cold water species;
data work.cold1;
    set work.predictcold;
    oldAcclimation_Temp=Acclimation_Temp;
    Acclimation_Temp=floor((Acclimation_Temp-32/1));
    format Acclimation_Temp Acclfmt.;

proc sort;
    by Acclimation_Temp;

*Check that acclimation temps are grouped into 1 degree intervals;
proc summary nway;
    class Acclimation_Temp;
    var oldAcclimation_Temp;
    output out=work.checkcold min=min max=max;

*Compute mean UILT for each species within each 1 degree interval;
proc summary nway data=work.cold1;
    class Acclimation_Temp Common_Name;
    var UILT;
    output out=work.umeanscold mean= n=nrec;

*Check median UILT and total number of species at each acclimation temp;
proc summary nway data=umeanscold;
    class Acclimation_Temp;
    var UILT;
    output out=work.check2cold median=median;


*Rank species by UILT at each acclimation temp;
Variable ranking will be percentile;
proc rank groups=100 data=work.umeanscold out=work.cold2;
    by Acclimation_Temp;
    var UILT;
    ranks ranking;

proc sort;
    by Acclimation_Temp ranking;


RUN;
```

Appendix 7

General Wisconsin Spawning Times of All Species Used in the Development of Sub-Lethal Criteria

Common Name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
alewife						y	y	y				
american brook lamprey				y	y	y						
banded darter				y	y	y						
banded killifish					y	y	y	y				
bigmouth buffalo				y	y	y						
bigmouth shiner					y	y	y	y				
black buffalo				y	y							
black bullhead				y	y	y	y	y				
black crappie					y	y	y					
black redhorse				y	y							
blackchin shiner						y	y	y				
blackfin cisco	y											y
blacknose dace				y	y	y	y					
blacknose shiner						y	y	y				
blackside darter				y	y	y						
blackstripe topminnow						y	y					
bloater	y	y	y									y
blue sucker				y	y	y						
bluegill					y	y	y	y				
bluntnose darter												
bluntnose minnow					y	y	y	y				
bowfin			y	y	y	y						
brassy minnow					y	y						
brook silverside					y	y	y	y				
brook stickleback			y	y	y	y	y					
brook trout									y	y	y	y
brown bullhead					y	y	y					
brown trout	y								y	y	y	y
bullhead minnow						y	y	y				
burbot	y	y	y									y
central mudminnow			y	y								
central stoneroller					y	y	y					
channel catfish					y	y	y					
chestnut lamprey				y	y							
chinook salmon									y	y	y	
cisco/lake herring											y	y
coho salmon									y	y	y	
common carp				y	y	y	y	y				
common shiner					y	y	y					
creek chub				y	y	y	y					
creek chubsucker												
crystal darter												
deepwater cisco								y	y			
deepwater sculpin	y	y										y
emerald shiner					y	y	y	y				
fantail darter				y	y	y						

Common Name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
fathead minnow					y	y	y	y				
finescale dace				y	y	y	y					
flathead catfish						y	y					
freshwater drum					y	y	y					
ghost shiner						y	y	y				
gilt darter						y						
gizzard shad				y	y	y	y	y				
golden redhorse					y							
golden shiner					y	y	y	y				
goldeye				y	y	y	y					
goldfish				y	y	y	y	y				
grass pickerel			y	y								
gravel chub				y								
greater redhorse					y	y	y					
green sunfish					y	y	y	y				
highfin carpsucker					y	y	y					
hornyhead chub					y	y	y					
iowa darter				y	y	y						
ironcolor shiner				y	y	y	y	y	y			
johnny darter				y	y	y						
kiyi										y	y	y
kokanee salmon												
lake chub				y	y	y						
lake chubsucker			y	y	y	y	y					
lake sturgeon				y	y	y						
lake trout									y	y	y	y
lake whitefish	y	y								y	y	y
largemouth bass				y	y	y	y					
largescale stoneroller					y	y						
least darter				y	y	y	y					
logperch				y	y	y	y					
longear sunfish					y	y	y	y				
longnose dace				y	y	y	y					
longnose gar					y	y	y					
longnose sucker				y	y							
mimic shiner					y	y	y					
mississippi silvery minnow				y	y	y	y					
mooneye				y	y							
mottled sculpin			y	y	y							
mud darter				y	y							
muskellunge				y	y							
ninespine stickleback						y	y					
northern brook lamprey				y	y	y						
northern hog sucker				y	y							
northern pike			y	y	y							
northern redbelly dace					y	y	y	y				
orangespotted sunfish					y	y	y	y				
ozark minnow					y	y	y					
paddlefish			y	y	y	y						
pallid shiner												
pearl dace			y	y	y	y						

Common Name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
pink salmon							y	y	y	y		
pirate perch					y							
pugnose minnow						y	y					
pugnose shiner					y	y	y					
pumpkinseed					y	y	y	y				
pygmy whitefish											y	y
quillback				y	y	y						
rainbow darter			y	y	y	y						
rainbow smelt			y	y	y							
rainbow trout	y	y	y	y	y							
red shiner					y	y	y	y	y			
redfin shiner						y	y	y				
redside dace					y	y						
river carpsucker					y	y						
river darter				y	y	y						
river redhorse					y							
rock bass					y	y						
rosyface shiner				y	y	y						
round whitefish	y									y	y	y
sand shiner					y	y	y	y				
sauger				y	y							
shorthead redhorse				y	y							
shortjaw cisco												
shortnose cisco				y	y	y						
shortnose gar					y	y	y					
shovelnose sturgeon				y	y	y						
silver chub					y	y	y	y				
silver lamprey				y	y	y						
silver redhorse				y	y							
skipjack herring												
slender madtom					y	y						
slenderhead darter						y						
slimy sculpin				y	y							
smallmouth bass					y	y						
smallmouth buffalo				y	y	y						
southern redbelly dace					y	y	y					
speckled chub					y	y	y	y				
spoonhead sculpin						y	y	y				
spotfin shiner					y	y	y	y	y			
spottail shiner					y	y	y	y				
spotted sucker				y	y							
starhead topminnow						y	y					
stonecat						y	y					
striped shiner					y	y						
suckermouth minnow							y	y				
tadpole madtom					y	y	y					
trout-perch					y	y	y	y				
walleye				y	y							
warmouth					y	y	y	y				
weed shiner						y	y					
western sand darter						y	y	y				

Common Name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
white bass				y	y	y						
white crappie					y	y						
white perch					y	y						
white sucker			y	y	y	y						
yellow bass					y	y						
yellow bullhead					y	y	y					
yellow perch				y	y	y						

Appendix 8

General Spawning Areas of Fish Species in Great Lakes Waters of Wisconsin

Species	S Green Bay	N Green Bay	N Lake Michigan	S Lake Michigan	Lake Superior	Chequamegon Bay
alewife	T & L	T & L	T & L	T & L	T & L	T & L
bloater	NA	L	L	L	L	NA
bluntnose minnow	L	L	L	L	L	L
bowfin	T & L	T & L	T & L	T & L	NA	NA
brook trout	NA	T	T	T	T	T
brown trout	NA	T & L	T & L	T & L	T	T
burbot	T	L	T & L	T & L	T & L	T & L
chinook salmon	NA	T	T	T	T	T
cisco/lake herring	NA	L	L	L	L	L
coho salmon	NA	T	T	T	T	T
common shiner	T & L	T & L	T & L	T & L	T & L	T & L
deepwater sculpin	NA	L	L	L	L	L
emerald shiner	L	L	L	L	L	L
fathead minnow	L	L	L	L	L	L
freshwater drum	T & L	T & L	T & L	T & L	NA	NA
gizzard shad	T	T	T	T	NA	NA
kiyi	NA	NA	NA	NA	L	NA
lake chub	NA	T & L	T & L	T	T & L	T & L
lake sturgeon	T & L	T	T & L	T & L	T & L	T & L
lake trout	L	L	L	L	L	L
lake whitefish	NA	T & L	L	L	L	L
longnose dace	L	L	L	L	NA	NA
longnose sucker	T	T	T & L	T	T	T
muskellunge	L	T & L	T & L	T & L	T & L	NA
ninespine stickleback	L	L	L	L	L	L
northern pike	T & L	T & L	T & L	T	T & L	T & L
pink salmon	L	L	L	L	T	T
rainbow smelt	T & L	T & L	T & L	T & L	T & L	T & L
rainbow trout	T	T	T	T	T	T
round whitefish	L	L	L	L	L	L
sauger	T & L	L	NA	NA	NA	NA
shortjaw cisco	NA	NA	NA	NA	L	NA
slimy sculpin	NA	L	L	L	L	L
smallmouth bass	T & L	T & L	T & L	T & L	T & L	L
spoonhead sculpin	NA	L	L	L	L	L
spottail shiner	L	L	L	L	L	L
trout-perch	T	T & L	T & L	L	L	T & L
walleye	T & L	T & L	T	T	T	T
white bass	L	T & L	T & L	T & L	T & L	T & L
white sucker	T	T & L	T & L	T	T & L	T & L
yellow perch	T & L	T & L	T & L	T & L	T & L	L

L = species spawns only in the lake, **T** = species spawns only in tributaries, **T & L** = species spawns in both the lake and tributaries
NA = species does not exist in the given Great Lakes region

The references for the information in this table are Goodyear et. al. 1982 vol. I, II, &IV and Becker 1983.

Appendix 9

Summary of Species Data Used for Development of Sub-Lethal Criteria for Maximum Spawning Temperature

113 Species **N data points = 338**

Rank	Common Name	Classification	n	Species Geometric Mean Temperature (°F)
1	burbot	cool/great lakes	2	**36.95**
2	kiyi	great lakes	1	**38.00**
3	round whitefish	great lakes	2	**40.00**
4	cisco/lake herring	cold/great lakes	3	**41.66**
5	deepwater sculpin	great lakes	1	**45.00**
6	slimy sculpin	cold/great lakes	2	**47.74**
7	lake whitefish	great lakes	6	**47.96**
8	chinook salmon	cold/great lakes	1	**50.00**
9	spoonhead sculpin	great lakes	1	**50.00**
10	coho salmon	cold/great lakes	3	**52.25**
11	brown trout	cold/great lakes	4	**52.42**
12	brook trout	cold/great lakes	5	**53.15**
13	lake chub	great lakes	3	**53.34**
14	sauger	warm/great lakes	8	**53.40**
15	grass pickerel	warm	2	**53.50**
16	river darter	warm	1	**54.00**
17	rainbow trout	cold/great lakes	6	**54.06**
18	lake trout	great lakes	8	**54.36**
19	northern pike	warm/great lakes	8	**54.67**
20	goldeye	warm	1	**55.00**
21	rainbow smelt	great lakes	5	**56.27**
22	silver redhorse	warm	2	**56.50**
23	walleye	warm/great lakes	9	**56.59**
24	yellow perch	warm/great lakes	15	**57.75**
25	pink salmon	great lakes stray	2	**57.92**
26	mooneye	warm	2	**57.99**
27	iowa darter	warm	1	**59.00**
28	logperch	warm	1	**59.00**
29	longnose sucker	cold/great lakes	1	**59.00**
30	mottled sculpin	cool	3	**59.96**
31	muskellunge	warm/great lakes	5	**60.00**
32	blue sucker	warm	1	**60.00**
33	central mudminnow	LFF	2	**60.00**
34	gravel chub	warm	1	**60.00**
35	paddlefish	warm	1	**61.00**
36	southern redbelly dace	warm	1	**61.00**
37	lake sturgeon	warm/great lakes	3	**61.93**
38	blackside darter	warm	1	**62.00**
39	ninespine stickleback	great lakes	1	**62.00**
40	shorthead redhorse	warm	2	**62.48**
41	white sucker	cool/great lakes_LFF	7	**63.60**
42	pearl dace	warm	1	**64.00**
43	spotted sucker	warm	3	**64.98**
44	trout-perch	warm/great lakes	6	**65.81**
45	bowfin	warm/great lakes	3	**66.00**
46	greater redhorse	warm	1	**66.00**
47	least darter	warm	2	**66.18**
48	longnose dace	warm/great lakes	5	**66.45**
49	brassy minnow	warm	2	**66.75**
50	brook stickleback	LFF	3	**67.31**
51	alewife	great lakes	8	**67.93**
52	gilt darter	warm	1	**68.00**
53	largescale stoneroller	warm	1	**68.00**
54	spottail shiner	warm/great lakes	4	**68.20**

Rank	Common Name	Classification	n	Species Geometric Mean Temperature (°F)
55	black crappie	warm	5	**68.40**
56	creek chub	warm_LFF	3	**68.58**
57	mississippi silvery minnow	warm	1	**69.00**
58	american brook lamprey	cool	1	**70.00**
59	johnny darter	warm	3	**70.00**
60	shovelnose sturgeon	warm	1	**70.00**
61	slenderhead darter	warm	1	**70.00**
62	yellow bass	warm	3	**70.64**
63	longnose gar	warm	2	**71.97**
64	smallmouth buffalo	warm	3	**71.99**
65	chestnut lamprey	warm	1	**72.00**
66	finescale dace	warm	1	**72.00**
67	golden redhorse	warm	2	**72.00**
68	lake chubsucker	warm	1	**72.00**
69	black redhorse	warm	2	**72.50**
70	northern brook lamprey	warm	2	**72.50**
71	northern hog sucker	warm	2	**72.50**
72	largemouth bass	warm	4	**72.51**
73	smallmouth bass	warm/great lakes	6	**72.51**
74	brook silverside	warm	3	**72.83**
75	rock bass	warm	3	**72.88**
76	gizzard shad	warm/great lakes	5	**72.95**
77	silver lamprey	warm	1	**73.00**
78	white crappie	warm	4	**73.00**
79	river carpsucker	warm	2	**73.99**
80	shortnose gar	warm	2	**74.00**
81	white bass	warm/great lakes	6	**74.22**
82	freshwater drum	warm/great lakes	6	**74.48**
83	fathead minnow	LFF/great lakes	7	**74.56**
84	river redhorse	warm	3	**75.00**
85	hornyhead chub	warm	1	**75.00**
86	spotfin shiner	warm	1	**75.00**
87	blacknose dace	warm_LFF	3	**75.04**
88	bigmouth buffalo	warm	4	**75.17**
89	common shiner	warm/great lakes	6	**75.36**
90	flathead catfish	warm	2	**75.99**
91	fantail darter	warm	2	**76.00**
92	suckermouth minnow	warm	1	**77.00**
93	golden shiner	LFF	3	**77.15**
94	brown bullhead	warm	2	**77.99**
95	warmouth	warm	1	**78.00**
96	banded killifish	warm	3	**78.28**
97	central stoneroller	warm	5	**78.35**
98	bluntnose minnow	warm/great lakes_LFF	4	**78.74**
99	bullhead minnow	warm	1	**79.00**
100	green sunfish	LFF	3	**79.60**
101	pumpkinseed	warm	6	**79.64**
102	rosyface shiner	warm	4	**80.09**
103	northern redbelly dace	warm	1	**81.00**
104	emerald shiner	warm/great lakes	2	**81.50**
105	highfin carpsucker	warm	1	**82.00**
106	quillback	warm	2	**82.00**
107	pugnose shiner	warm	1	**84.00**
108	channel catfish	warm	4	**84.25**
109	longear sunfish	warm	4	**84.38**
110	bluegill	warm	5	**84.68**
111	red shiner	warm stray	1	**85.00**
112	orangespotted sunfish	warm	2	**89.00**

113	sand shiner	warm	3	**89.03**

Appendix 10

Sub-Lethal Maximum No Growth Temperature Data

		N data points =	124	N species =	27
ID	Common Name	Classification	n	High No Growth Temp (degree F)	Species Geo Mean
199	alewife	great lakes	6	71.60	**77.45**
200	alewife	great lakes		71.60	
197	alewife	great lakes		77.00	
198	alewife	great lakes		78.60	
195	alewife	great lakes		83.40	
196	alewife	great lakes		83.40	
4	black crappie	warm	4	79.00	**82.94**
5	black crappie	warm		81.00	
1	black crappie	warm		86.00	
326	black crappie	warm		86.00	
203	bloater	great lakes	4	69.80	**73.80**
204	bloater	great lakes		73.40	
201	bloater	great lakes		75.20	
202	bloater	great lakes		77.00	
16	bluegill	warm	6	80.00	**91.11**
257	bluegill	warm		86.00	
258	bluegill	warm		91.40	
255	bluegill	warm		95.00	
298	bluegill	warm		97.10	
256	bluegill	warm		98.60	
338	brook trout	cold/great lakes	4	66.00	**68.53**
23	brook trout	cold/great lakes		68.10	
341	brook trout	cold/great lakes		70.00	
339	brook trout	cold/great lakes		70.10	
333	brown trout	cold/great lakes	4	67.00	**71.97**
276	brown trout	cold/great lakes		68.00	
346	brown trout	cold/great lakes		70.10	
32	brown trout	cold/great lakes		84.00	
38	channel catfish	warm	4	93.10	**94.54**
296	channel catfish	warm		93.10	
294	channel catfish	warm		95.00	
37	channel catfish	warm		97.00	
207	chinook salmon	cold/great lakes	5	55.40	**65.18**
208	chinook salmon	cold/great lakes		64.40	
318	chinook salmon	cold/great lakes		66.00	
205	chinook salmon	cold/great lakes		69.80	
206	chinook salmon	cold/great lakes		71.60	
211	coho salmon	cold/great lakes	5	59.00	**67.90**
212	coho salmon	cold/great lakes		68.00	
209	coho salmon	cold/great lakes		69.80	
210	coho salmon	cold/great lakes		71.60	

ID	Common Name	Classification	n	High No Growth Temp (degree F)	Species Geo Mean
316	coho salmon	cold/great lakes		72.00	
65	emerald shiner	warm/great lakes	1	84.00	**84.00**
69	fathead minnow	LFF/great lakes	1	90.00	**90.00**
245	finescale dace	warm	4	84.20	**84.20**
246	finescale dace	warm		84.20	
248	finescale dace	warm		84.20	
247	finescale dace	warm		84.20	
77	green sunfish	LFF	1	93.10	**93.10**
261	largemouth bass	warm	7	89.60	**93.49**
259	largemouth bass	warm		89.60	
262	largemouth bass	warm		93.20	
260	largemouth bass	warm		93.20	
312	largemouth bass	warm		96.00	
311	largemouth bass	warm		96.00	
88	largemouth bass	warm		97.10	
98	muskellunge	warm/great lakes	5	86.10	**88.87**
227	muskellunge	warm/great lakes		87.80	
229	muskellunge	warm/great lakes		87.80	
228	muskellunge	warm/great lakes		91.40	
230	muskellunge	warm/great lakes		91.40	
107	northern pike	warm/great lakes	7	75.00	**84.10**
102	northern pike	warm/great lakes		81.50	
103	northern pike	warm/great lakes		82.00	
225	northern pike	warm/great lakes		86.00	
223	northern pike	warm/great lakes		86.00	
224	northern pike	warm/great lakes		89.60	
226	northern pike	warm/great lakes		89.60	
243	northern redbelly dace	warm	4	84.20	**84.20**
241	northern redbelly dace	warm		84.20	
244	northern redbelly dace	warm		84.20	
242	northern redbelly dace	warm		84.20	
218	rainbow smelt	great lakes	6	60.80	**66.79**
217	rainbow smelt	great lakes		60.80	
216	rainbow smelt	great lakes		64.40	
215	rainbow smelt	great lakes		64.40	
213	rainbow smelt	great lakes		75.20	
214	rainbow smelt	great lakes		77.00	
221	rainbow trout	cold/great lakes	7	64.40	**72.25**
222	rainbow trout	cold/great lakes		71.60	
125	rainbow trout	cold/great lakes		72.00	
331	rainbow trout	cold/great lakes		73.00	
124	rainbow trout	cold/great lakes		75.00	
219	rainbow trout	cold/great lakes		75.20	
220	rainbow trout	cold/great lakes		75.20	
132	sauger	warm/great lakes	1	79.00	**79.00**
233	smallmouth bass	warm/great lakes	6	89.60	**93.32**
234	smallmouth bass	warm/great lakes		93.20	
ID	Common Name	Classification	n	High No Growth Temp (degree F)	Species Geo Mean

231	smallmouth bass	warm/great lakes		93.20	
232	smallmouth bass	warm/great lakes		94.00	
299	smallmouth bass	warm/great lakes		95.00	
136	smallmouth bass	warm/great lakes		95.00	
149	spottail shiner	warm/great lakes	2	93.00	**94.04**
147	spottail shiner	warm/great lakes		95.10	
158	walleye	warm/great lakes	12	68.00	**80.82**
254	walleye	warm/great lakes		80.60	
251	walleye	warm/great lakes		80.60	
252	walleye	warm/great lakes		80.60	
253	walleye	warm/great lakes		80.60	
152	walleye	warm/great lakes		81.00	
159	walleye	warm/great lakes		81.00	
249	walleye	warm/great lakes		82.40	
250	walleye	warm/great lakes		82.40	
343	walleye	warm/great lakes		84.00	
154	walleye	warm/great lakes		84.00	
345	walleye	warm/great lakes		86.10	
163	white bass	warm/great lakes	2	66.00	**79.18**
287	white bass	warm/great lakes		95.00	
324	white crappie	warm	3	81.00	**81.99**
167	white crappie	warm		81.00	
322	white crappie	warm		84.00	
291	white sucker	cool/great lakes_LFF	4	84.00	**85.25**
175	white sucker	cool/great lakes_LFF		85.00	
289	white sucker	cool/great lakes_LFF		86.00	
290	white sucker	cool/great lakes_LFF		86.00	
187	yellow perch	warm/great lakes	9	82.00	**87.28**
239	yellow perch	warm/great lakes		82.40	
240	yellow perch	warm/great lakes		82.40	
236	yellow perch	warm/great lakes		89.60	
237	yellow perch	warm/great lakes		89.60	
238	yellow perch	warm/great lakes		89.60	
235	yellow perch	warm/great lakes		89.60	
186	yellow perch	warm/great lakes		90.00	
321	yellow perch	warm/great lakes		91.00	

Appendix 11

Sub-Lethal Maximum Gametogenesis Temperature Data

COLD Waters

ID	Common Name	Classification	Temperature (F) Low	Temperature (F) High	Gametogensis Notes
12	brook trout	cold/great lakes		61.00	mean temp that should not be exceeded the month prior to spawning to ensure functional maturation
11	brook trout	cold/great lakes		66.00	summer mean water temp that should not be exceeded since gametogenesis occurs throughout the growing season
1	brook trout	cold/great lakes		67.90	represents criteria for gonadal growth phase in summer (actually <20 C), fall-spring spawners
3	cisco/lake herring	cold/great lakes		67.90	represents criteria for gonadal growth phase in summer (actually <20 C)
2	rainbow trout	cold/great lakes		67.90	represents criteria for gonadal growth phase in summer (actually <20 C)
4	white sucker	cool/LFF/great lakes		53.90	represents criteria for gonadal growth phase in fall & winter (actually <12 C), spring spawners

WARM & LFF Waters

ID	Common Name	Classification	Temperature (F) Low	Temperature (F) High	Gametogensis Notes
7	bluegill	warm	54.10		represents criteria for gonadal growth phase during long days (actually >12 C), spring-fall spawners
6	largemouth bass	warm	54.10		represents criteria for gonadal growth phase during long days (actually >12 C), spring-fall spawners
5	northern pike	warm/great lakes		53.90	represents criteria for gonadal growth phase in fall & winter (actually <12 C), spring spawners
9	walleye	warm/great lakes		50.00	"near" the upper limit for a winter minimum for gonad maturation
4	white sucker	cool/LFF/great lakes		53.90	represents criteria for gonadal growth phase in fall & winter (actually <12 C), spring spawners
10	yellow perch	warm/great lakes		54.00	no viable spawning when mainatained at 12 C or higher, optimum = 6 C (43 F)
8	yellow perch	warm/great lakes		50.00	"near" the upper limit for a winter minimum for gonad maturation

GREAT LAKES Waters

ID	Common Name	Classification	Temperature (F) Low	Temperature (F) High	Gametogensis Notes
12	brook trout	cold/great lakes		61.00	mean temp that should not be exceeded the month prior to spawning to ensure functional maturation
11	brook trout	cold/great lakes		66.00	summer mean water temp that should not be exceeded since gametogenesis occurs throughout the growing season
1	brook trout	cold/great lakes		67.90	represents criteria for gonadal growth phase in summer (actually <20 C), fall-spring spawners
3	cisco/lake herring	cold/great lakes		67.90	represents criteria for gonadal growth phase in summer (actually <20 C)
5	northern pike	warm/great lakes		53.90	represents criteria for gonadal growth phase in fall & winter (actually <12 C), spring spawners
2	rainbow trout	cold/great lakes		67.90	represents criteria for gonadal growth phase in summer (actually <20 C)
9	walleye	warm/great lakes		50.00	"near" the upper limit for a winter minimum for gonad maturation
4	white sucker	cool/LFF/great lakes		53.90	represents criteria for gonadal growth phase in fall & winter (actually <12 C), spring spawners
10	yellow perch	warm/great lakes		54.00	no viable spawning when mainatained at 12 C or higher, optimum = 6 C (43 F)
8	yellow perch	warm/great lakes		50.00	"near" the upper limit for a winter minimum for gonad maturation

The references for the information in this table are Hokanson 1973 and Hokanson 1977.

Appendix 12

Visual Explanations of How the Final Default Sub-Lethal Criteria are Developed

The tables in this appendix are visual examples presented to help explain how the final default sub-lethal criteria were developed, as explained in (and to be used with) the *Final Default Sub-Lethal Criteria* section on page 21. The development of the cold water criteria are used in this appendix, but serve as an example of how the criteria were developed for all other water uses or communities.

Use of Individual Monthly Values for Determination of Pre-Final Sub-Lethal Thermal Water Quality Criteria - Cold Water Example

Month	Ta	Acute c	Sub-Lethal c	GM c	SP c	GR c
January	35	68	47		47	
February	36	68	45		45	
March	39	69	53		53	
April	47	70	59		59	
May	56	72	59		59	72
June	62	72	67		67	72
July	64	73	68	68		
August	63	73	68	68		
September	57	72	57	68	52	
October	49	70	52		52	
November	41	69	50		50	
December	37	69	46		46	

Explanations:
Ta = Ambient Temperature
GM = refers to proposed Maximum Gametogenesis Temperature criteria.
SP = refers to proposed Maximum Spawning Temperature criteria.
GR = refers to proposed Maximum No Growth Temperature criteria - geometric mean method.
c = new proposed criterion (for each endpoint).

All temperatures are in degree Fahrenheit.

Acute criteria are implemented as daily maximum values.
Sub-lethal criteria are implemented as 7-day average values.
The acute criterion will always be underlying the sub-lethal criterion.
When the acute & sub-lethal criteria for a month are the same, the acute criterion drives the month (sub-lethal criterion not used).

#	= criteria that are adjusted to solve the problems of sub-lethal criteria less than ambient or greater than acute criteria.

Finalization of Sub-Lethal Thermal Water Quality Criteria - Cold Water Example

Month	Ta	A	A SL	O SL	F SL
January	35	68	47		46.6
February	36	68	45		46.7
March	39	69	53		51.1
April	47	70	59		57.2
May	56	72	59		62.9
June	62	72	67		66.6
July	64	73	68		67.3
August	63	73	68		64.9
September	57	72	57	52	59.8
October	49	70	52		53.3
November	41	69	50		47.9
December	37	69	46		46.6

Explanations:

Ta = refers to ambient temperature.

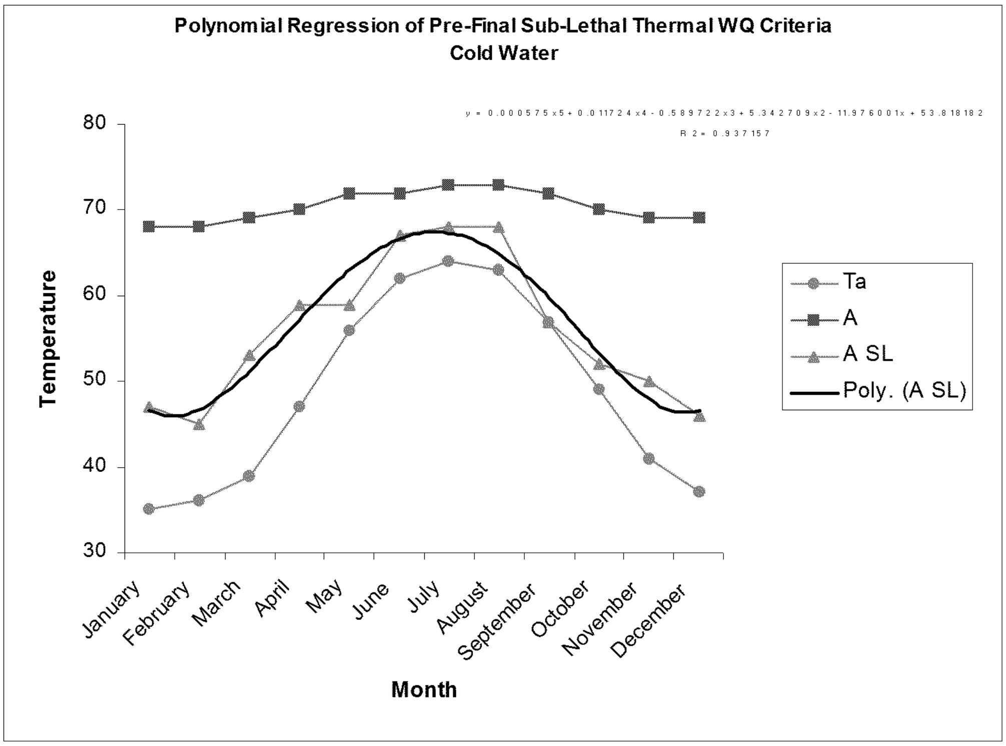
A = refers to acute temperature criteria.

A SL = refers to the prefinal sub-lethal temperature criteria following any adjustments (from prefinal step) shown as highlighted values.

O SL = refers to the originally developed sub-lethal temperature criteria (values shown only if an adjustment was made).

F SL = refers to the **final sub-lethal temperature criteria** derived from the application of the polynomial regression equation (below).

All temperatures are in degree Fahrenheit.



Acute criteria are implemented as daily maximum values.
Sub-lethal criteria are implemented as 7-day average values.
The acute criterion will always be underlying the sub-lethal criterion.

The trendline is a predicted sub-lethal curve via a 5 factor polynomial regression of the adjusted/prefinal sub-lethal criteria, expressed as:

y = 0.000575x5 + 0.011724x4 - 0.589722x3 + 5.342709x2 - 11.976001x + 53.818182

Appendix 13

Derivation of the Exponent "a" in the Inland Lake, Impoundment, and Great Lakes Water Bodies Conservative Heat Loss Analysis Equation

The purpose of this appendix is to detail the complete derivation of the exponent "a" in the inland lake, impoundment, and Great Lakes water body conservative heat loss analysis equations (reasonable potential and WQBEL calculations) from the equation presented in the "Industrial Waste Guide on Thermal Pollution" (Federal Water Pollution Control Administration [FWPCA] September 1968, pg. 102 - which is referenced as Edinger and Geyer 1965, pg. 113), which is the original source for the approach used in the current thermal rule, to the equation used in the current thermal rule.

Exponent "a" is in the following equations in the current rule:

$$T_p = [(WQC- T_a)/(e^{-a})] + T_a \qquad \text{AND} \qquad WQBEL = [(WQC- T_a)/(e^{-a})] + T_a$$

All the variables in these equations are defined in the "Default Reasonable Potential Calculations" and "Default Water Quality-Based Effluent Limitation Calculations" sections of this TSD.

The equation for the exponent "a" in the "Industrial Waste Guide on Thermal Pollution" is $a = (K)(A) \div [(P)(C_p)(Q)]$, and the equation for "a" in the current rule is $a = [(A)(54.7 + B(150))] \div [(8{,}360{,}000)(Q_e)]$, where:

K = energy exchange coefficient ($BTU/ft^2/day/°F$) = $[15.7 + (0.26 + B)((b)(W))]$
b = experimental evaporation coefficient = 15
W = wind speed = 10 miles/hour
B = a coefficient presented on page 97 of the FWPCA document & in tables in the TSD
A = area of the mixing zone (ft^2)
P = density of water = 62.49 lb/ft^3
C_p = specific heat of water = 1 BTU/lb/°F
Q = effluent volume or flow (ft^3/day)
Q_e = effluent flow (millions of gallons/day or mgd)

Thus:

$$(K)(A) \div [(P)(C_p)(Q)] = \mathbf{a} = [(A)(54.7 + B(150))] \div [(8{,}360{,}000)(Q_e)]$$

Numerator	Denominator
K = (54.7 + B(150)	$[(P)(C_p)(Q)] = [(8{,}360{,}000)(Q_e)]$
[15.7 + (0.26 + B)((b)(W))] = (54.7 + B(150)	$[(62.49)(1)(Q)] = [(8{,}360{,}000)(Q_e)]$
thus:	Must get the effluent flow variables in the same units,
[15.7 + (0.26 +B)((15)(10))]	thus:
[15.7 + ((0.26)(150) + (B)(150))]	1 ft^3/day = 0.000011574 ft^3/sec, following:
[15.7 + 39 + (B)(150)]	1 ft^3/day x day/24 hr x hr/60 min x min/60 sec
[54.7 + (B)(150)]	1 mgd = 1.54837 ft^3/sec, thus:
	1.54837 ft^3/sec ÷ 0.000011574 ft^3/sec = 133,780 mgd
	thus:
	$[(62.49)(1)(133{,}780)] \approx 8{,}360{,}000$

REFERENCES

Black, E.C. 1953. Upper lethal temperatures of some British Columbia freshwater fishes. *J. Fish. Res. Bd. Canada*. 10(4):196-210.

Brattstrom, B.H. 1968. Thermal acclimation in anuran amphibians as a function of latitude and altitude. *Comparative Biochemistry and Physiology*. 24:93-111.

Brungs, W.A., & B.R. Jones. 1977. Temperature Criteria for Freshwater Fish: Protocol and Procedures. U.S. EPA, Environmental Research Laboratory, Duluth, MN. EPA-600/3-77-061. 130 pp.

Becker, G.C. 1983. Fishes of Wisconsin. The University of Wisconsin Press, Madison, WI. 1053 pp.

Cairns, J., Jr. 1956. Effects of increased temperatures on aquatic organisms. *Industrial Wastes*. 1(4):150-152.

Christoffel, R., R. Hay, & M. Monroe. 2002. Turtles & Lizards of Wisconsin. Wisconsin Department of Natural Resources, Bureau of Endangered Resources, PUB-ER-104 2002. 48 pp.

Christoffel, R., R. Hay, & M. Wolfgram. 2001. Amphibians of Wisconsin. Wisconsin Department of Natural Resources, Bureau of Endangered Resources, PUB-ER-105 2001. 44 pp.

Coutant, C.C. 1970. Thermal pollution – biological effects: a review of the literature of 1969. *J. Water Poll. Contr. Fed*. 42(6):1025-1057.

Edinger, J.E. and J.C. Geyer. 1965. Heat Exchange in the Environment. Edison Electric Institute Publication No. 65-902.

Federal Water Pollution Control Administration. 1968. Industrial Waste Guide on Thermal Pollution. U.S. Department of the Interior, Corvallis, OR. 112 pp.

Fry, F.E.J., J.R. Brett, & G.H. Clawson. 1942. Lethal limits of temperature for young goldfish. Rev. Can. Biol. 1(1):50-56.

Fry, F.E.J., J.S. Hart, & K.F. Walker. 1946. Lethal Temperature Relations for a Sample Young Speckled Trout, *Salvelinus fontinalis*. Pb1. Ont. Fish. Res. Lab. No. 66, Univ. of Toronto Stud, Biol. Ser. No. 54, University of Toronto Press.

Giattinna, J.D. and R.R. Garton. 1982. Graphical model of thermoregulatory behaviour by fishes with a new measure of eurythermality. *Can. J. Fish. Aquat. Sci*. 39:524-528.

Goodyear, C.D., T.A. Edsall, D.M. Ormsby Dempsey, G.D. Moss, & P.E. Polanski. 1982. Atlas of the Spawning and Nursery Areas of Great Lakes Fishes Volume I - A Summary by Geographic Area. FWS/OBS-82/52, Office of Biological Services, Fish & Wildlife Service, U.S. Dept. of the Interior, Washington, DC. 147 pp.

Goodyear, C.D., T.A. Edsall, D.M. Ormsby Dempsey, G.D. Moss, & P.E. Polanski. 1982. Atlas of the Spawning and Nursery Areas of Great Lakes Fishes Volume II - Lake Superior. FWS/OBS-82/52, Office of Biological Services, Fish & Wildlife Service, U.S. Dept. of the Interior, Washington, DC. 114 pp.

Goodyear, C.D., T.A. Edsall, D.M. Ormsby Dempsey, G.D. Moss, & P.E. Polanski. 1982. Atlas of the Spawning and Nursery Areas of Great Lakes Fishes Volume IV - Lake Michigan. FWS/OBS-82/52, Office of Biological Services, Fish & Wildlife Service, U.S. Dept. of the Interior, Washington, DC. 201 pp.

Harrahy, E. 2007. Personal Communication. Wisconsin Department of Natural Resources, Madison, Wisconsin.

Hay, B. 2007. Personal Communication. Wisconsin Department of Natural Resources, Madison, Wisconsin.

Herreid, C.F. & S. Kinney. 1967. Temperature and development of the wood frog, *Rana sylvatic*, in Alaska. *Ecology*. 48:579-590.

Hokanson, K.E.F., J.H. McCormick, B.R. Jones, & J.H. Tucker. 1973. Thermal requirements for maturation, spawning, and embryo survival of the brook trout, *Salvelinus fontinalis*. *J. Fish. Res. Board Can.* 30(7):975-984.

Hokanson, K.E.F. 1977. Temperature requirements of some percids and adaptations to the seasonal temperature cycle. *J.Fish. Res. Board Can.* 34:1524-1550.

Houston, A.H. 1982. Thermal Effects Upon Fishes. Report NRCC No. 18566. National Research Council of Canada. Associate Committee on Scientific Criteria for Environmental Quality. 200 pp.

Imlay, M. 1969. Comment during discussion following Ruth Patrick presentation. In P.A. Krenkel and F.L. Parker (eds), Biological Aspects of Thermal Pollution, Proceedings of the National Symposium on Thermal Pollution, Sponsored by the Federal Water Pollution Control Administration and Vanderbilt University, Portland, Oregon, June 3-5, 1968. Vanderbilt University Press: pp. 161-198.

McCauley, R.W. 1981. Laboratory studies on directive and acute lethal effects of temperature on alewife (*Alosa pseudoharengus*) and rainbow smelt (*Osmerus mordax*) collected at Pickering GS. In A.E. Christie (ed), Biological Investigations to Improve Once-Through Cooling System Designs for the Great Lakes. Report No. 81481. Enviro. Stud. And Assess. Dept. Design and Development Div., Ontario Hydro, Dec. 1981, Toronto, Ontario: pp H1-H27.

Parker, G.E.. 1967. The influence of temperature and thyroxin on oxygen consumption in *Rana pipiens* tadpoles. *Copiea.* 1967:610-616.

Patrick, R. 1969. Some effects of temperature on freshwater algae. In P.A. Krenkel and F.L. Parker (eds), Biological Aspects of Thermal Pollution, Proceedings of the National Symposium on Thermal Pollution, Sponsored by the Federal Water Pollution Control Administration and Vanderbilt University, Portland, Oregon, June 3-5, 1968. Vanderbilt University Press: pp. 161-198.

Prescott, G.W. 1968. The Algae: A Review. Houghton Mifflin Company, Boston, MA. 436 pp.

Wallace, N.M. 1955. The Effects of Temperature on the Growth of Some Freshwater Diatoms. Notulae Naturae of the Academy of Natural Sciences of Philadelphia, No. 280. 11 pp.

Wisconsin Department of Natural Resources. 1995. Thermal Standards TAC Meeting Minutes, June 14, 1995.

Wismer, D.A. & A.E. Christie. 1987. Temperature Relationships of Great Lakes Fishes: A Data Compilation. Special Publication No. 87-3, Great Lakes Fishery Commission, Ann Arbor, MI. 195 pp.